Jet Structure topical group report

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co-convener with
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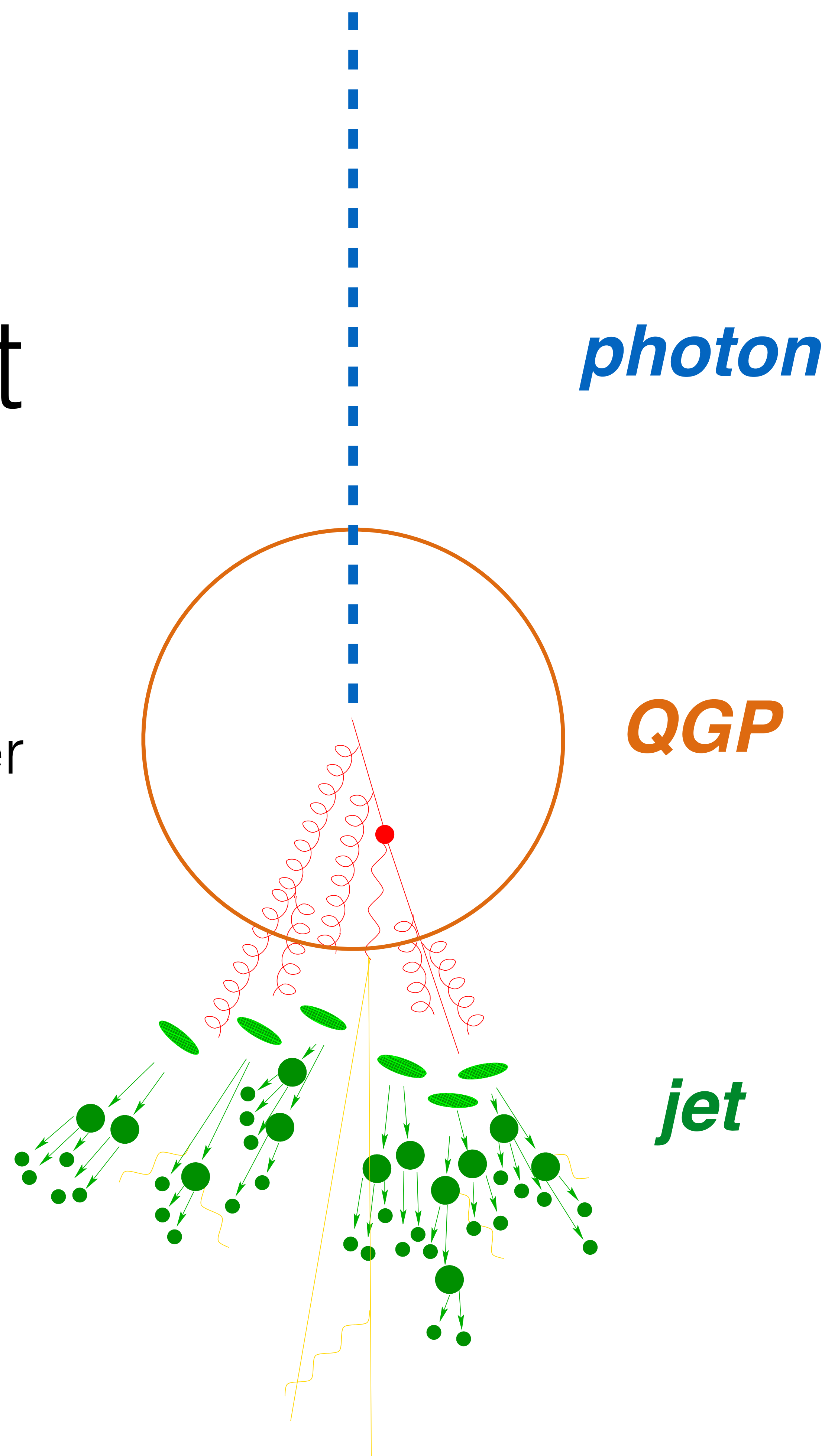
3rd sPHENIX Collaboration Meeting
Georgia State University



National Nuclear Physics Summer School
University of Colorado Boulder
9-22 July 2017

Organizers:

Ed Kinney
Jamie Nagle
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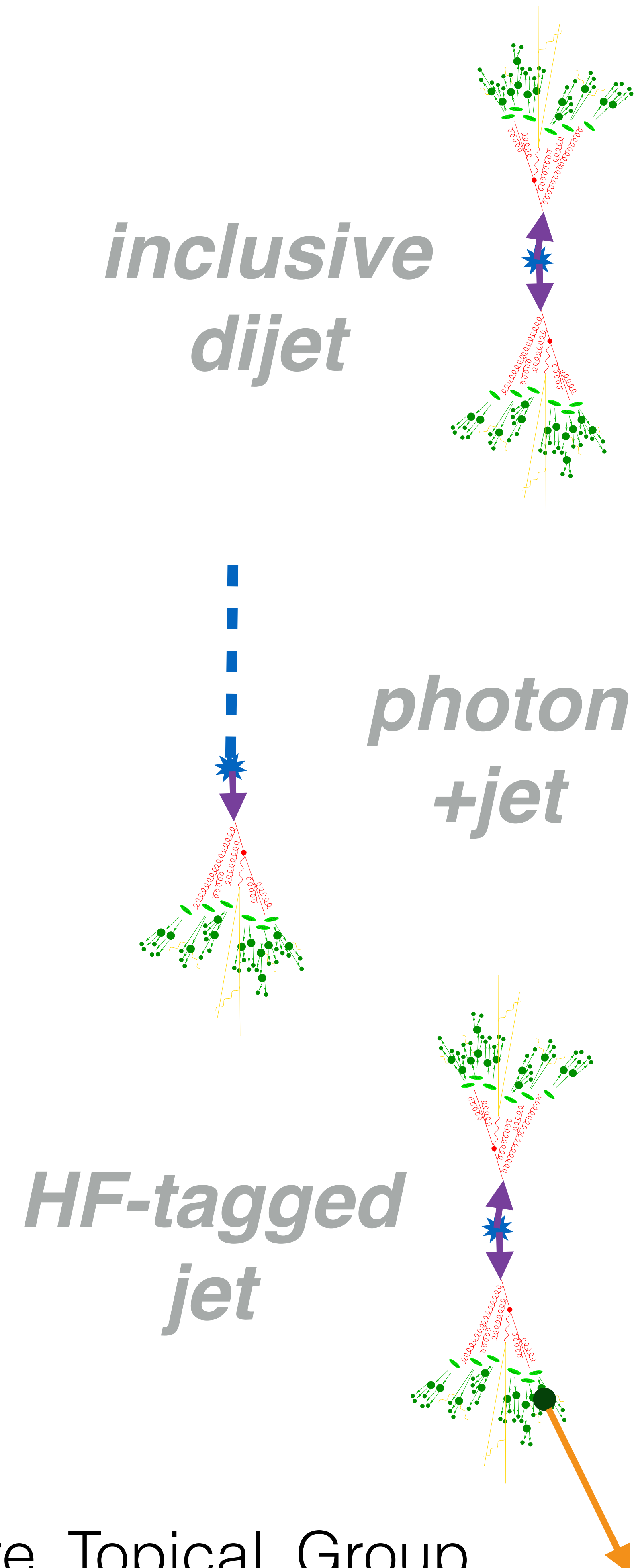
Paul Romatschke

More information TBA

1. Role of the Jet Structure topical group
2. The evolving physics picture
3. Summary of activities in the TG
4. Future activities (where to get involved!)
5. Plan for Quark Matter



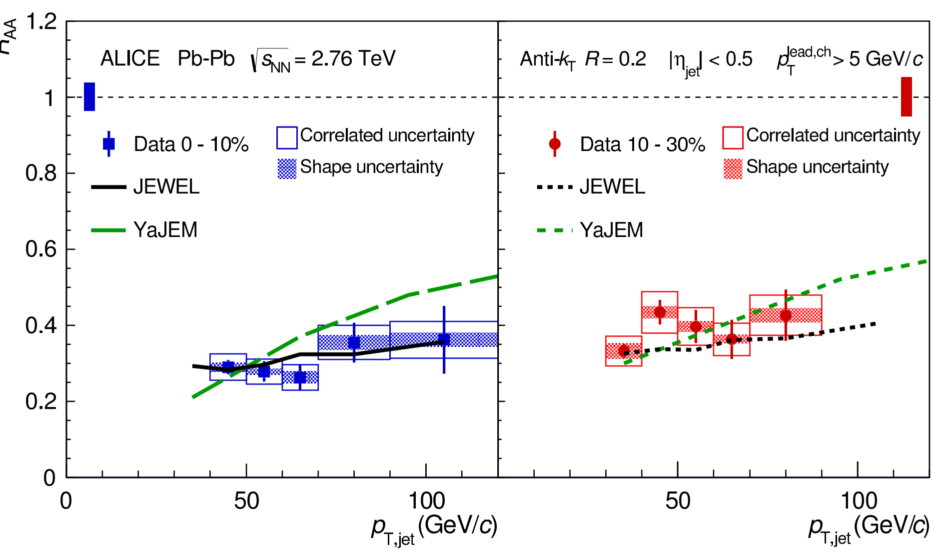
https://wiki.bnl.gov/sPHENIX/index.php/Jet_Structure_Topical_Group

1. Role of JS Topical Group

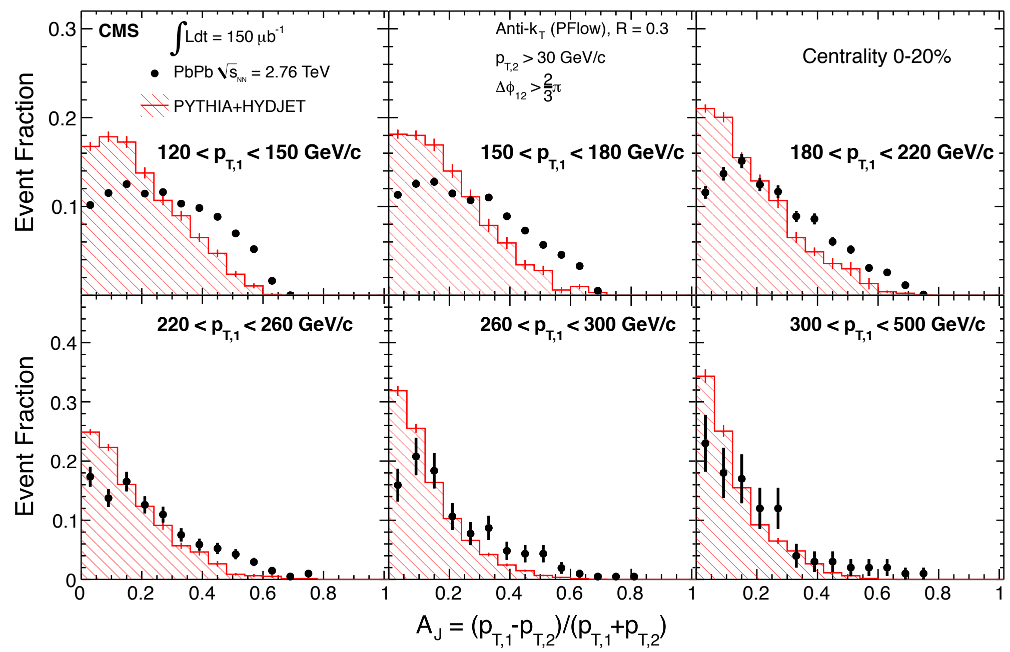
- *Performance*:
  - ➡ quantify sPHENIX experimental capabilities
  - ➡ provide guidance to Collaboration for design decisions / reviews
- *Physics:*
  - ➡ keep abreast of scientific developments
  - ➡ determine where our physics program can be most impactful
- *Simulations/software*:
  - ➡ keep up with / test latest updates in the simulations framework
  - ➡ develop tools for eventual analyzers
- *Organizational/support*:
  - ➡ provide plots/input for sPHENIX talks/posters/proceedings/reviews

How do we accomplish these effectively with existing person-power?

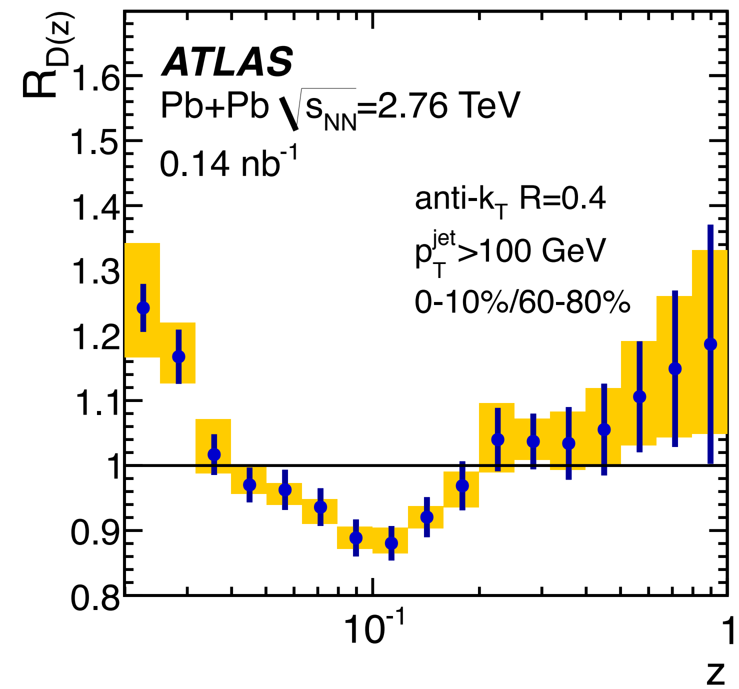
2. “early Run 1” era jet physics



inclusive jet suppression



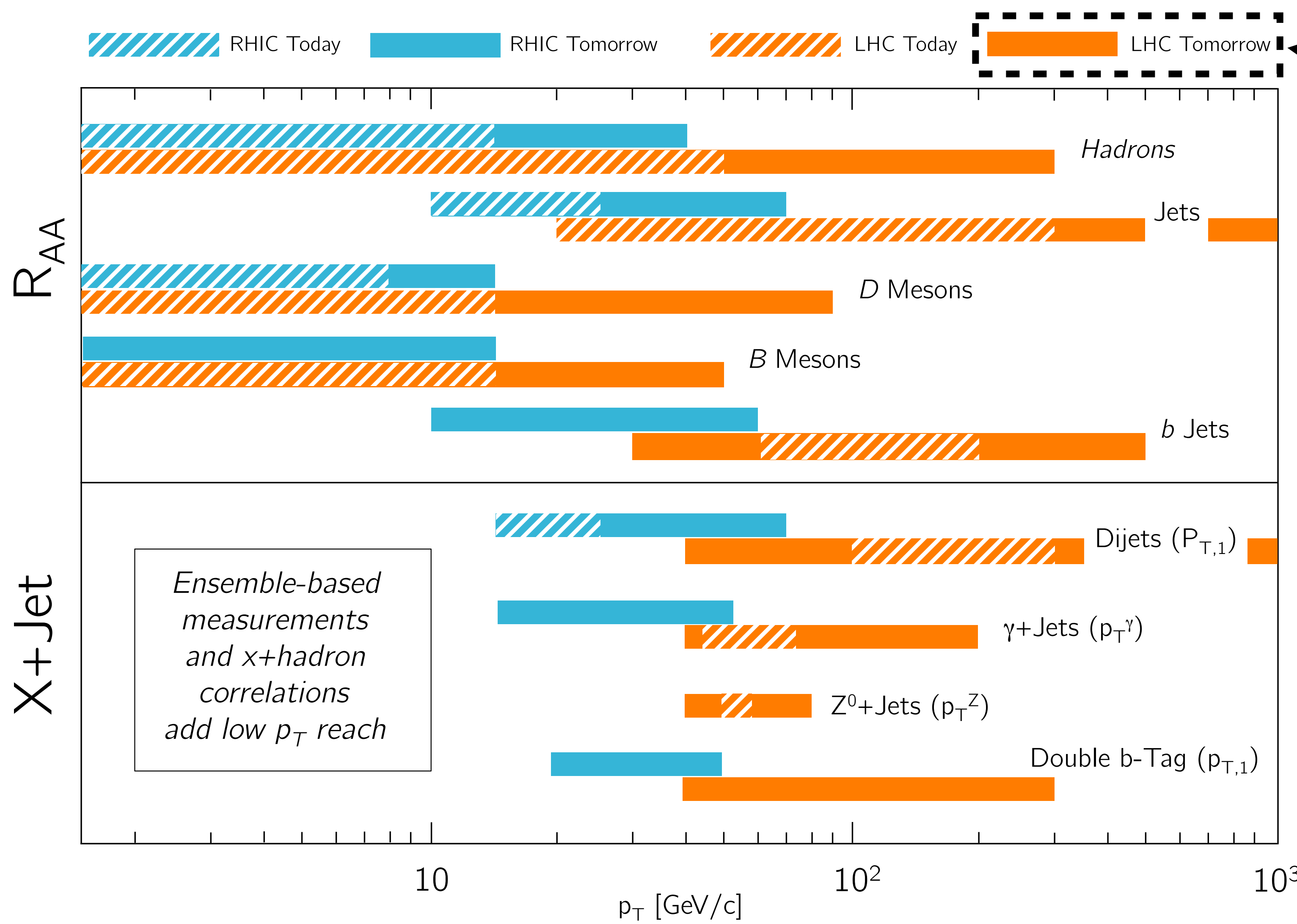
dijet p_T balance



fragmentation function ratios

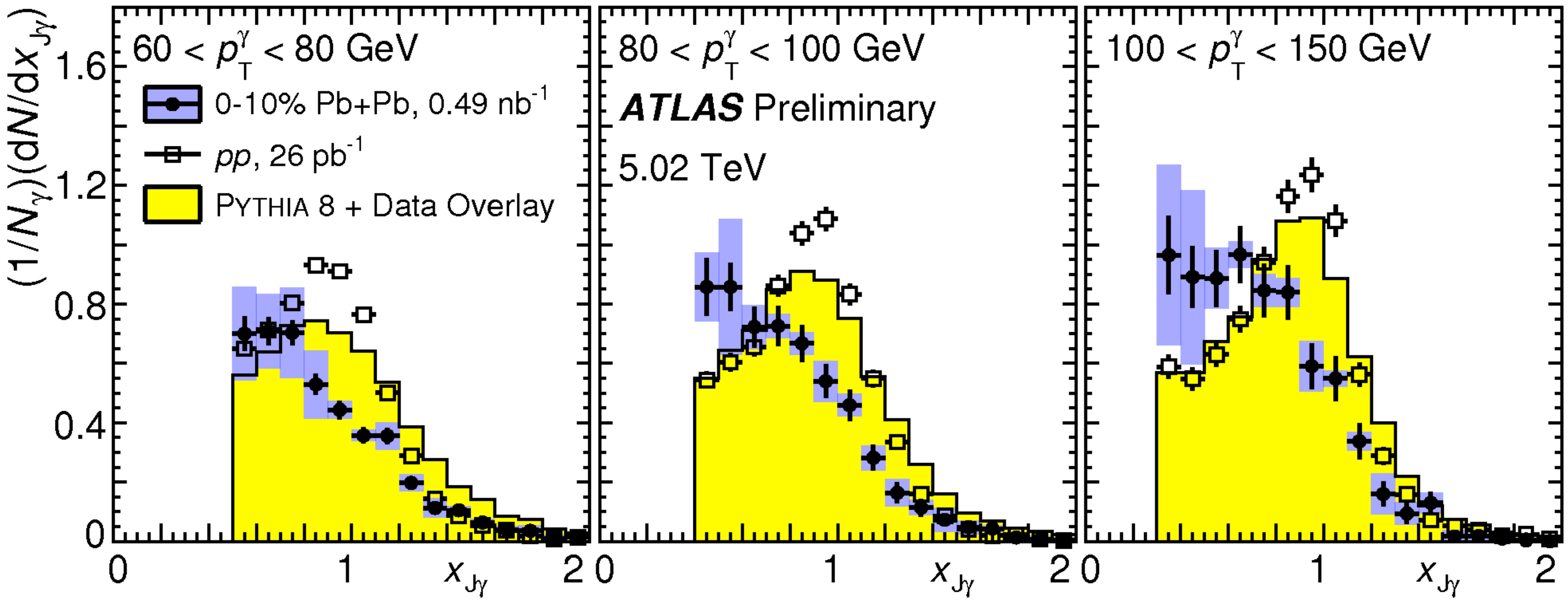
- Jet spectra (R_{AA}, recoil jet spectrum, early *b*-jets, etc.)
- Di-jets (multi-jet, missing p_T flow, early γ+jet, etc.)
- Fragmentation functions (jet+track correlations, etc.)

2. Jet physics during LHC Run 2



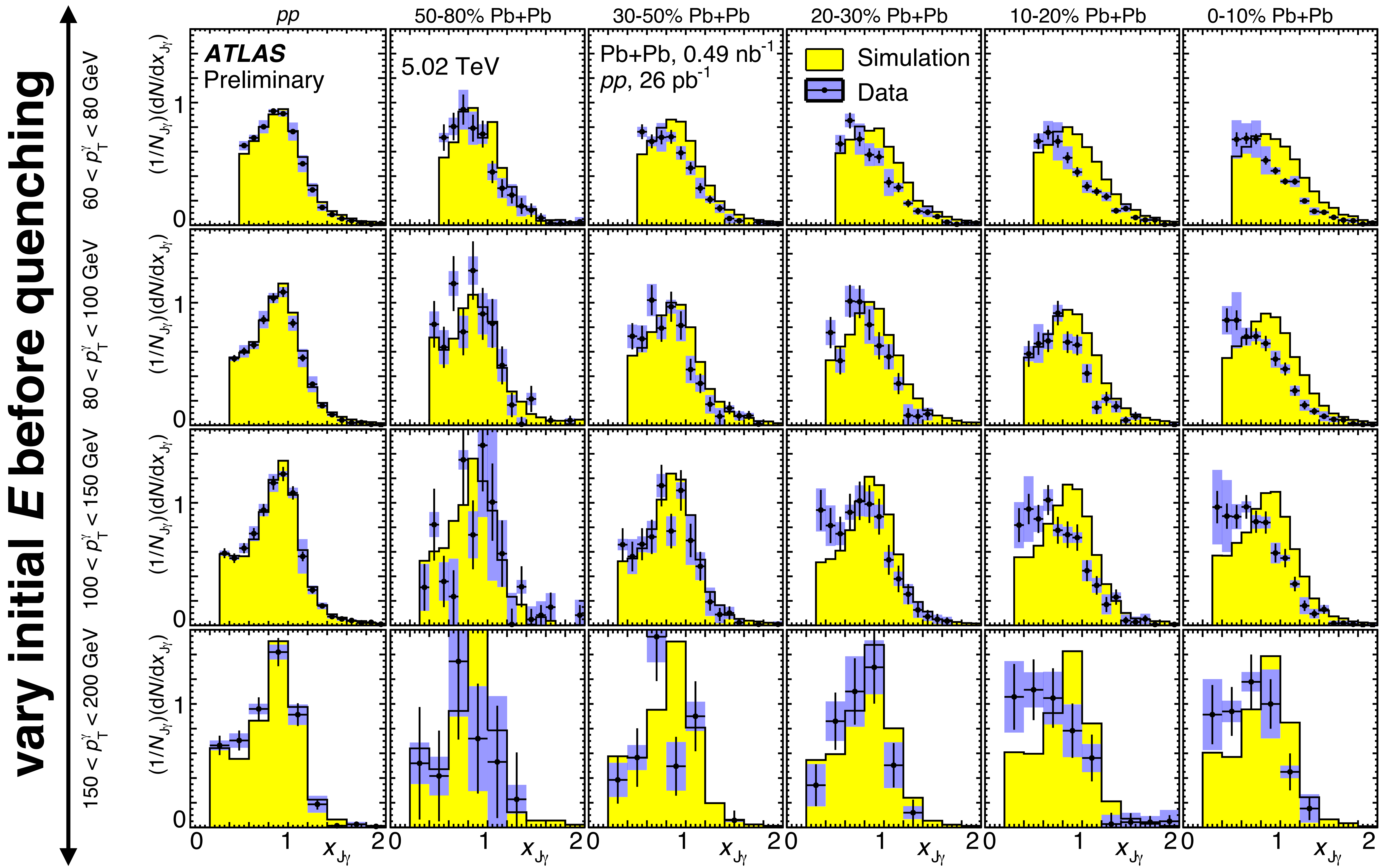
- Since then, developments in two major categories:
  - ➡ rarer probes (high-statistics for photons, *b*-jets)
  - ➡ extreme kinematic reach (charged particle & jet spectra)
  - ➡ new substructure observables (mass, z_g, others)

2. Photon-jet physics in Run 2



- Photon grants external handle on initial hard scattering
  - ➡ no surface bias
  - ➡ tests absolute *E*-loss (c.f. A_J sensitive to relative jet-to-jet difference in *E*-loss)
  - ➡ can make “apples to apples” *pp* to Pb+Pb comparisons
  - ➡ handle on light quark jet *E*-loss, connection b/w RHIC & LHC

vary system size

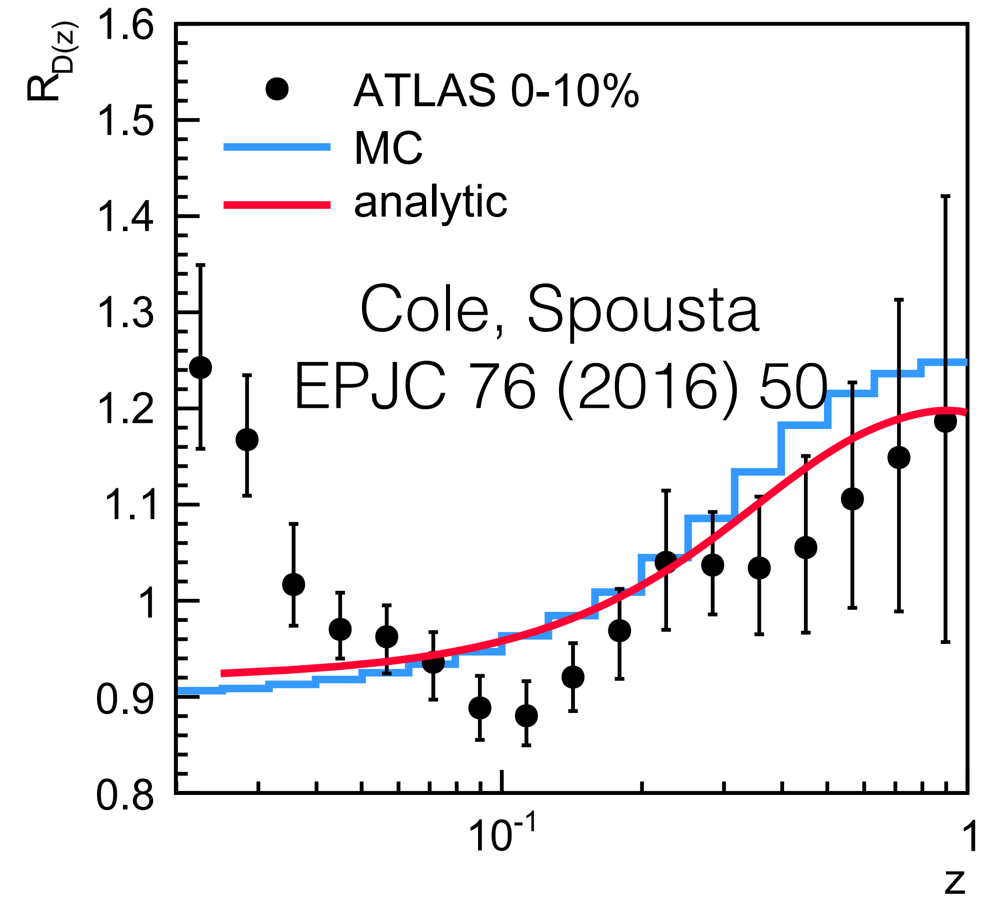


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-110/

2. Photon-tagged FF

$$R_{D(z)} = \frac{D(z;\, p_T^{\text{jet}}) \text{ in A+A}}{D(z;\, p_T^{\text{jet}}) \text{ in } p{+}p}$$

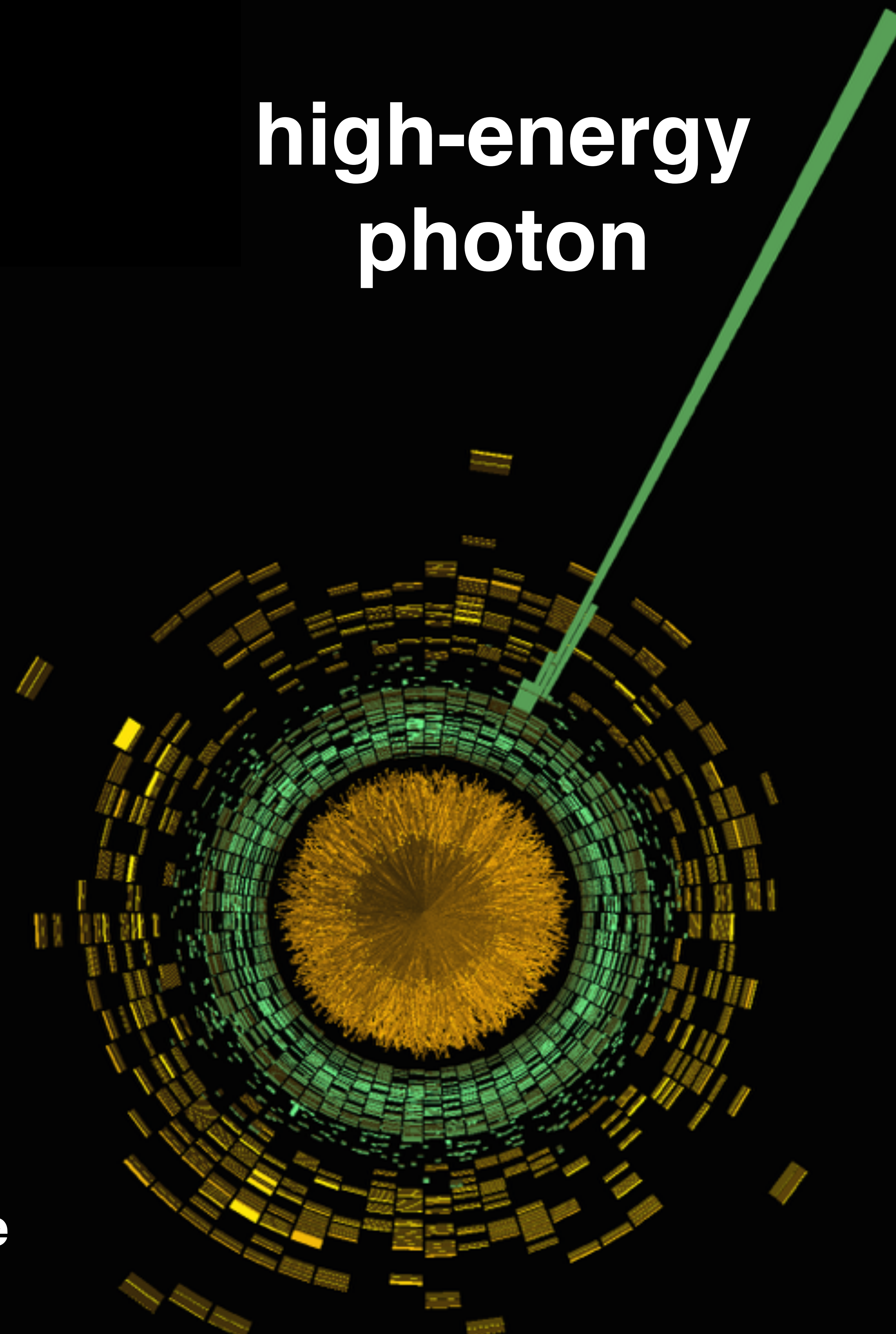
after quenching



- In typical FF measurements, implicit flavor difference between jets in the numerator and denominator
  - ➡ may cause artificial features in, e.g. D(z) ratio
  - ➡ measure distribution of $p_T^{\text{hadron}}/p_T^{\text{jet}}$, but in photon-containing events
- Together, <u>*photon+jet p_T balance*</u> & <u>*photon-tagged FF*</u> separate overall *E*-loss from medium-induced modification of fragmentation
  - ➡ existing γ+*h* measurements at RHIC muddle these two effects

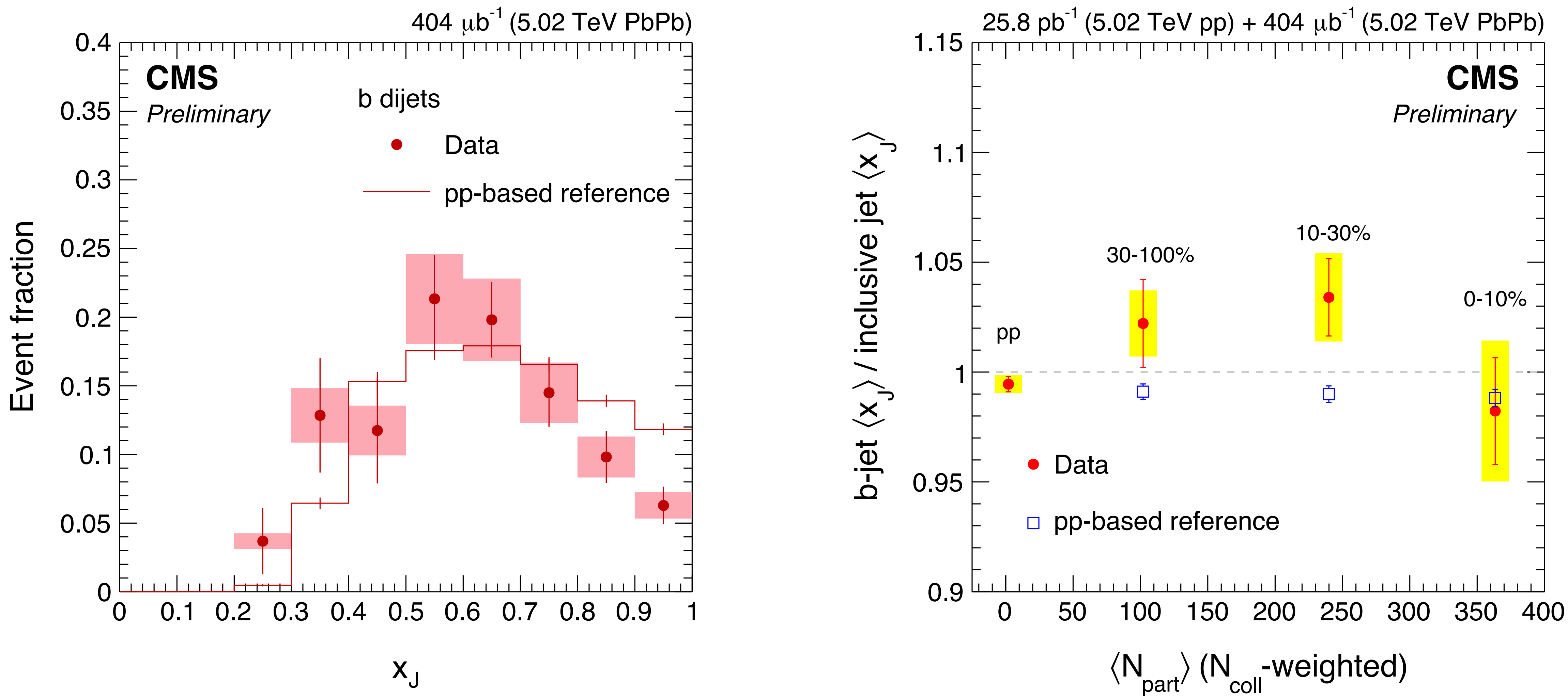
ATLAS EXPERIMENT

Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST
Pb+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
photon + multijet event
ΣE_T^{FCal} = 4.06 TeV

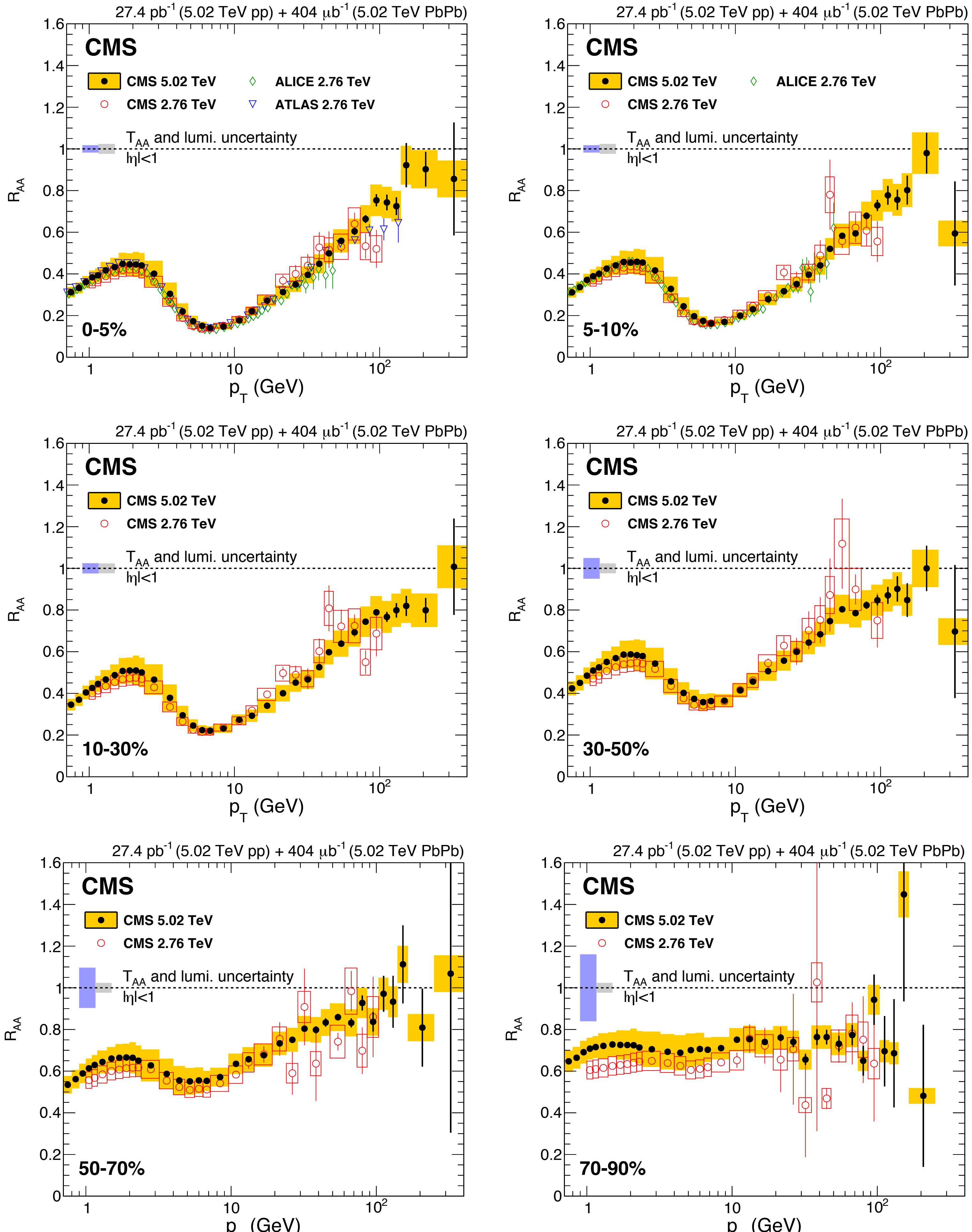


1. **ɣ+jet: absolute E-loss**
2. **ɣ+jet vs. reaction plane**
3. **ɣ-tagged R_{AA}**
4. **missing-p_T flow w/ external scale**
5. **D(z) for Pb+Pb jets with same flavor & original p_T as in p+p**

2. di-*b*-jet asymmetry

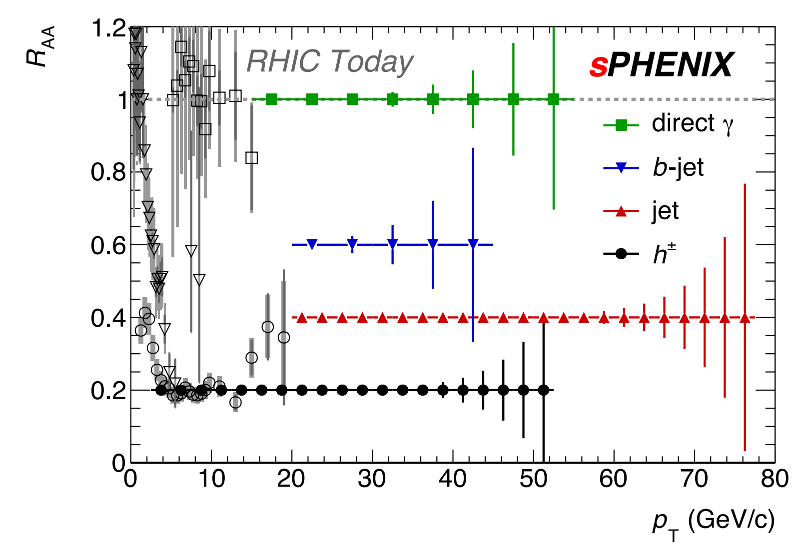


- Back-to-back *b*-jets enhance contribution of “flavor creation” processes relative to inclusive *b*-jets
  - ➡ indication of more balanced pairs than inclusive jets
  - ➡ but $p_{T,1} > 100$ GeV, $p_{T,2} > 40$ GeV
- Larger *b*-jet yields: more opportunities to repeat differential analyses we’ve done with inclusive jets

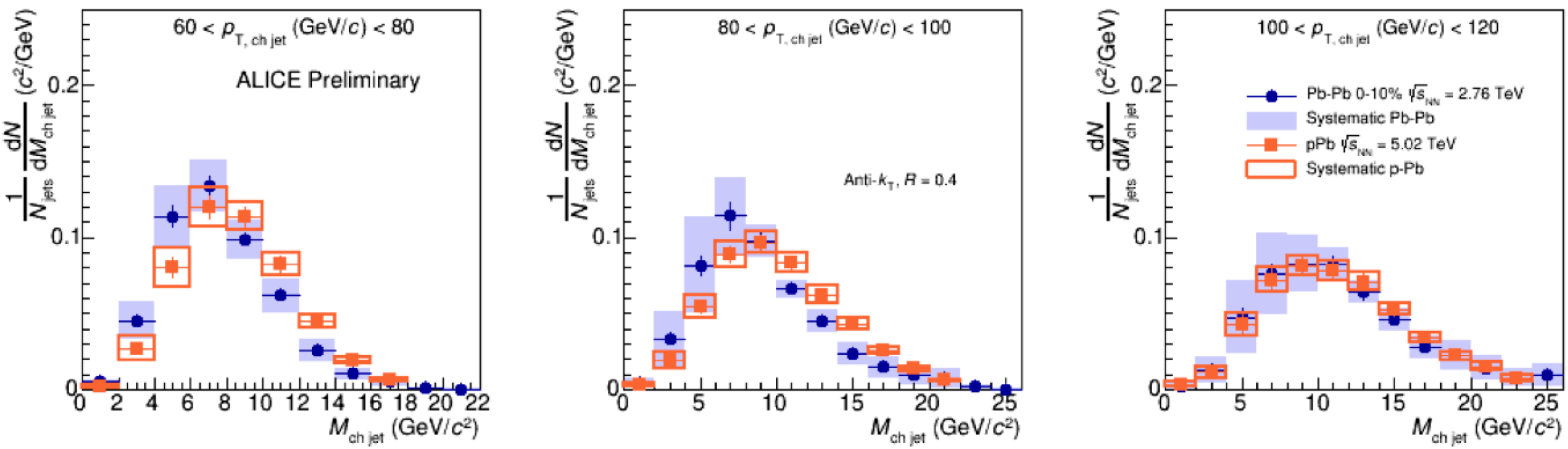


2. Extreme kinematic reach

- Charged hadron R_{AA} → 1 at p_T > 200 GeV?
  - ➡ also interesting to see R_{AA} for TeV-scale jets
- *Remember*: 50 GeV reach in charged hadrons for sPHENIX

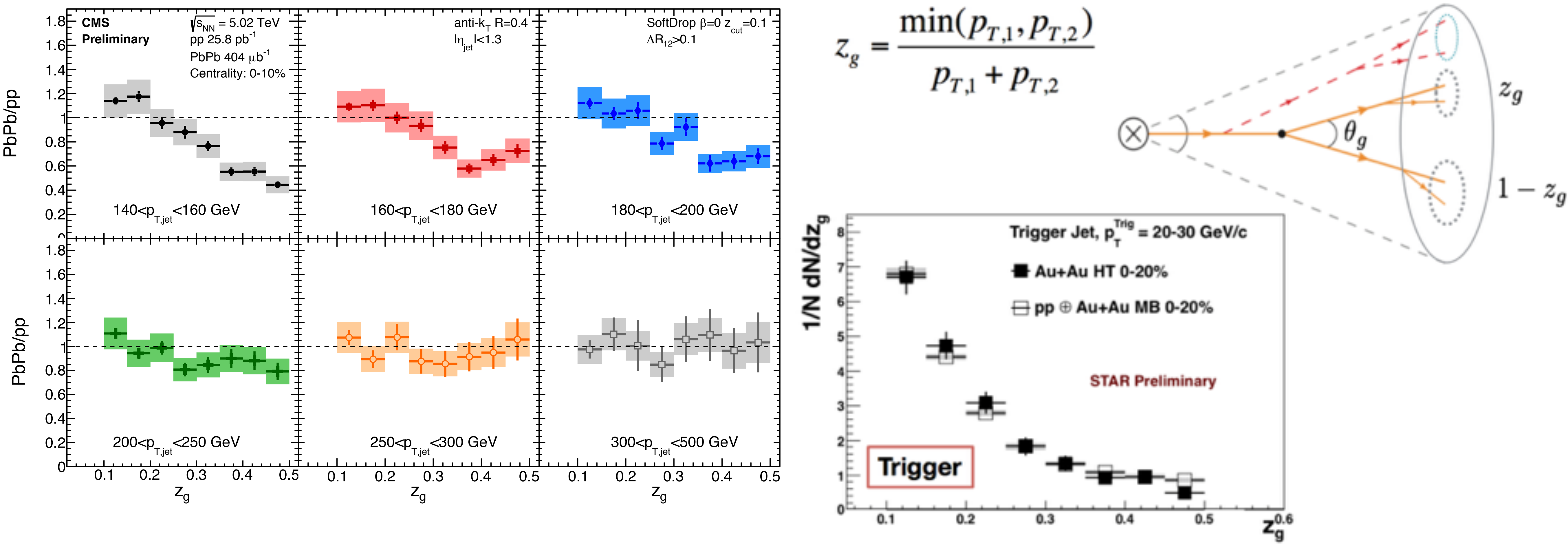


2. Jet substructure: mass



- Charged-jet results from ALICE: noticeable depletion of mass distribution at fixed (post-quenching) jet p_T
- Physics connection: depletion of mass from in-medium virtuality evolution?
  ➡ challenge to TG: how different is calo-only vs. particle-flow methods for a mass measurement?

2. Jet substructure: z_g

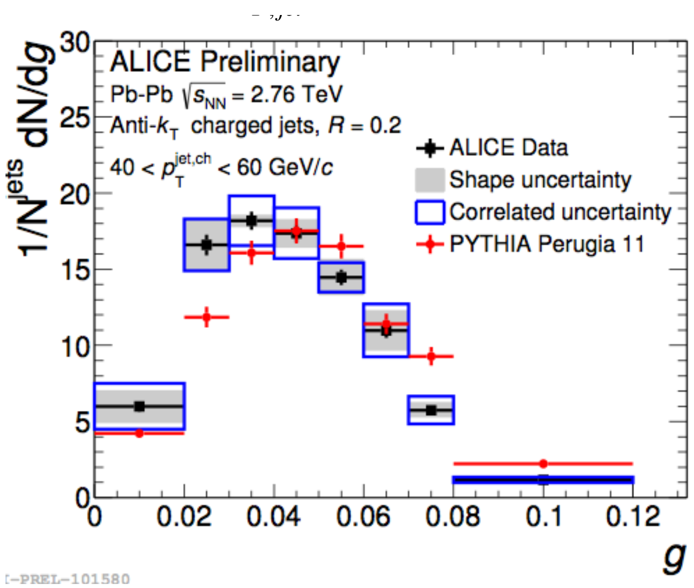


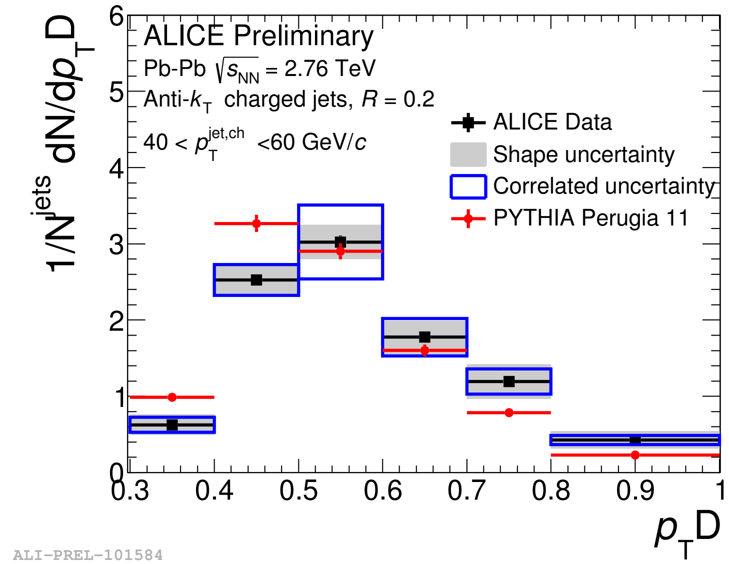
- Measurement of z_g, which in vacuum is sensitive to first branching in the parton shower

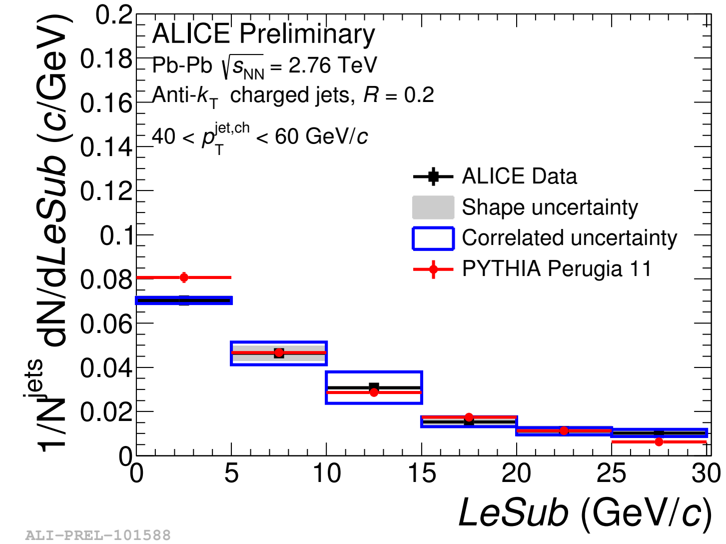
  ➡ systematic modification vs. centrality at the LHC

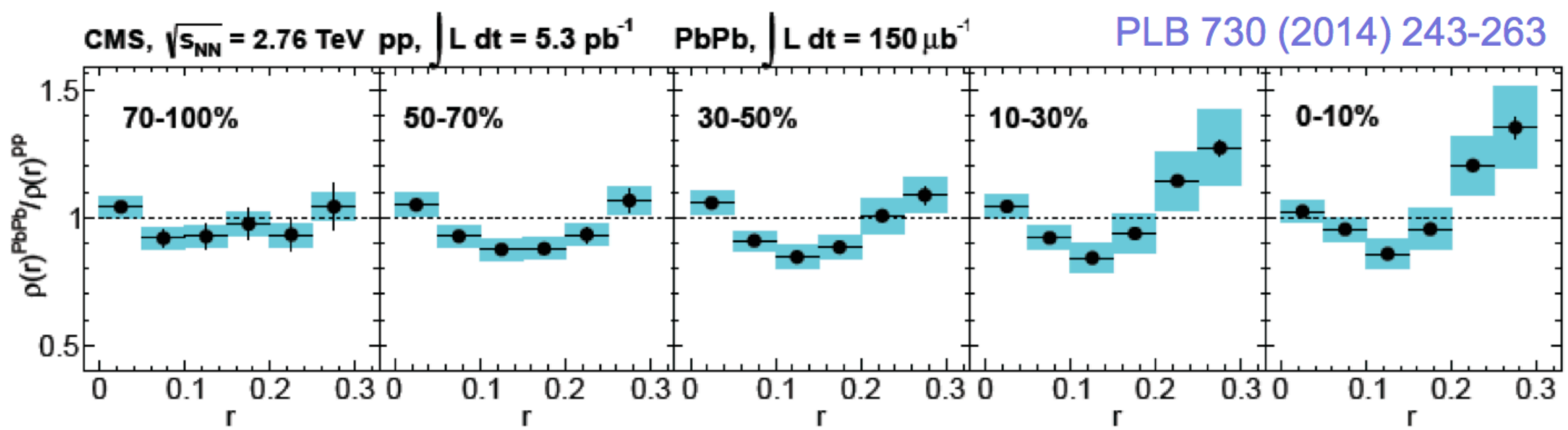
- Physics connection: sensitivity to coherent or de-coherent energy loss of parton shower in medium

2. Jet substructure







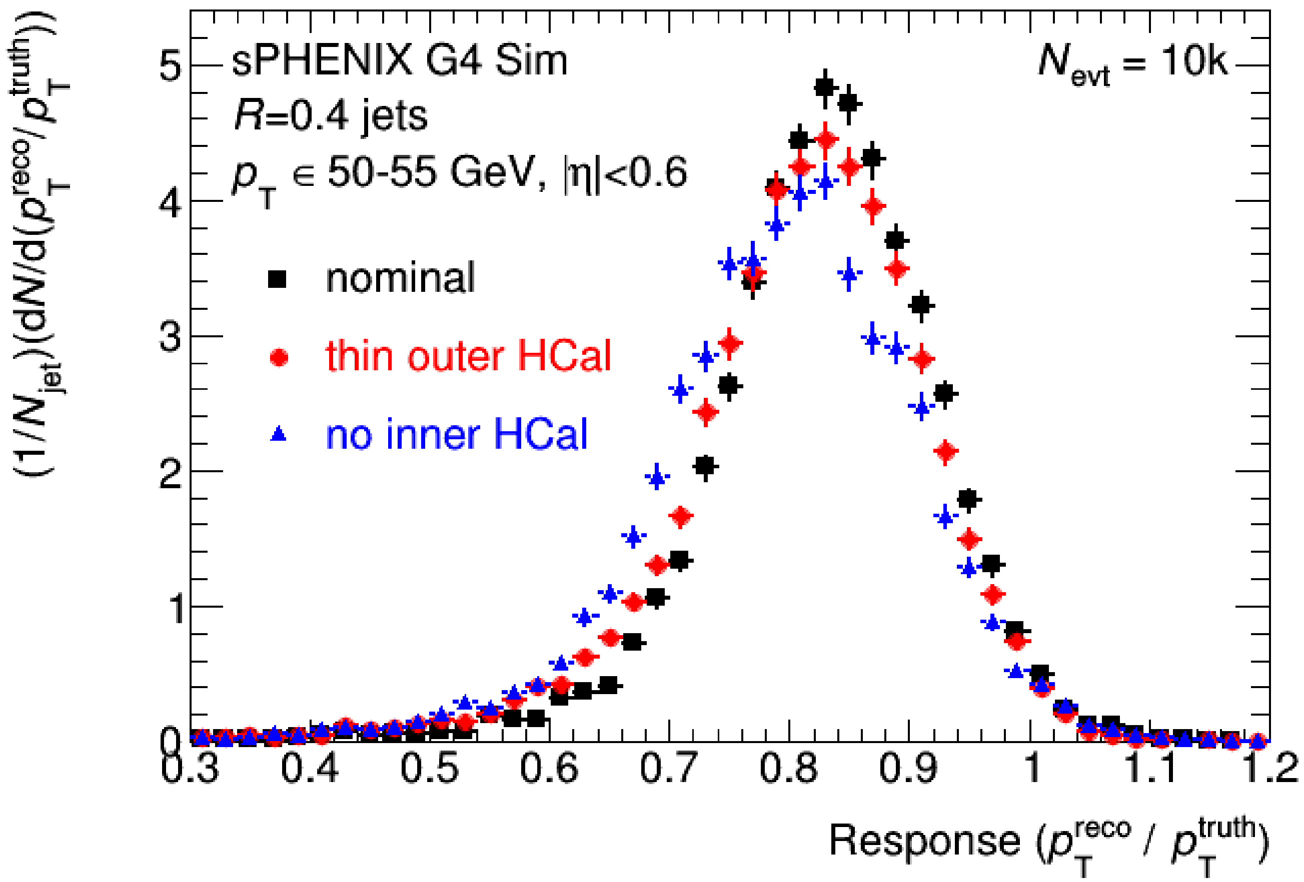


- Others which are not as "directly" connectable to underlying physics (IMO) but potentially useful nevertheless
  - ➡ challenge for TG: which are most useful for quantifying / disambiguating jet quenching at RHIC?

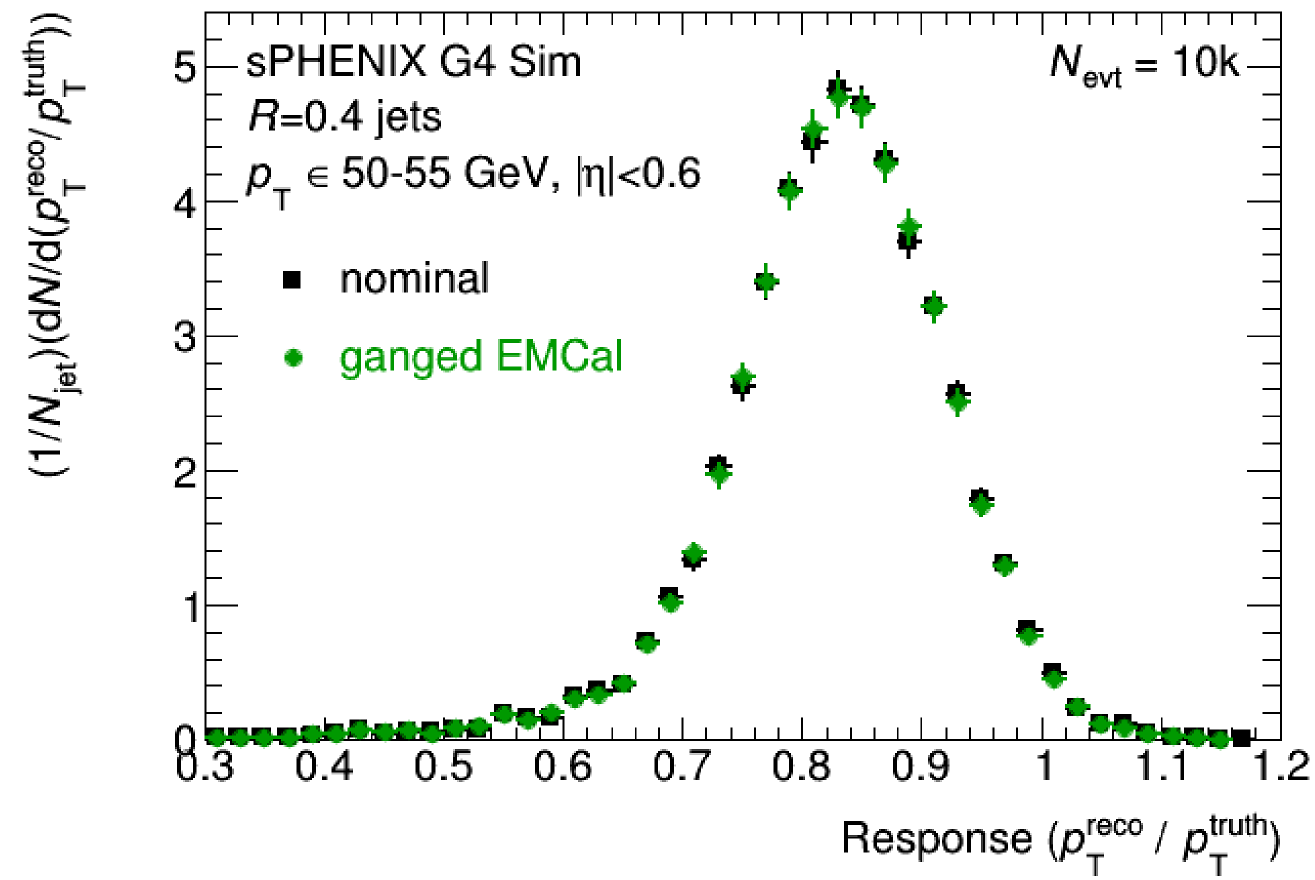
3. Summary of activities in the TG since last Collaboration Meeting

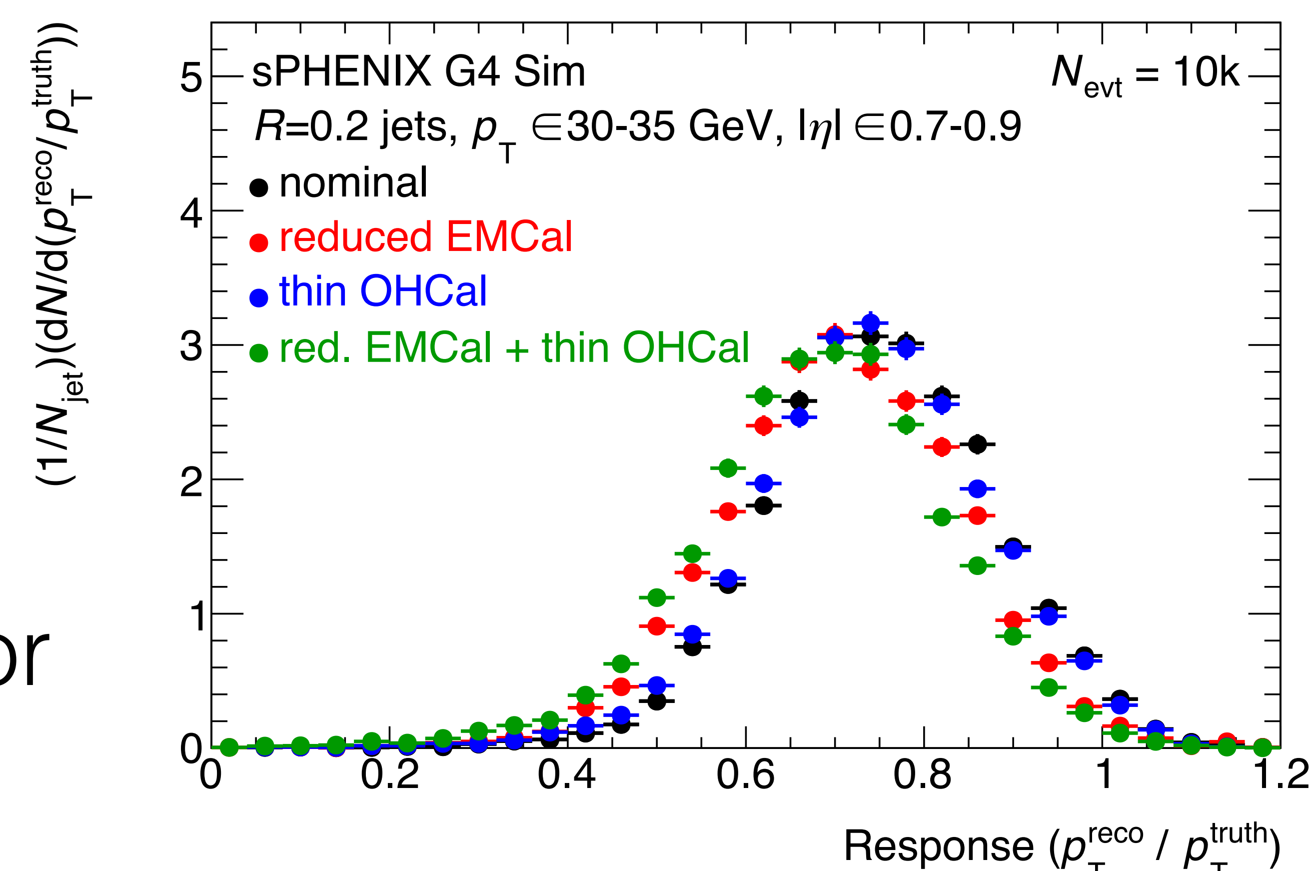
1. Jet & hadron response, FF, unfolding studies
   - ➡ initially motivated as a response to ALD de-scoping Charge
   - ➡ excellent opportunity to test software framework
   - ➡ many contributors — Rosi, Kurt, Megan, Sarah, Jamie, DVP
2. Clustering — Justin & Ohio U group, Brandon & MIT group
3. Updated studies of jet performance (systematic in collision system, eta, p_T, cone size, etc.) — Megan
4. Discussion of Particle Flow algorithm in HI collisions — Yen-Jie
5. Additional physics discussion / brainstorming — Rosi, DVP, others

3. Jet response studies

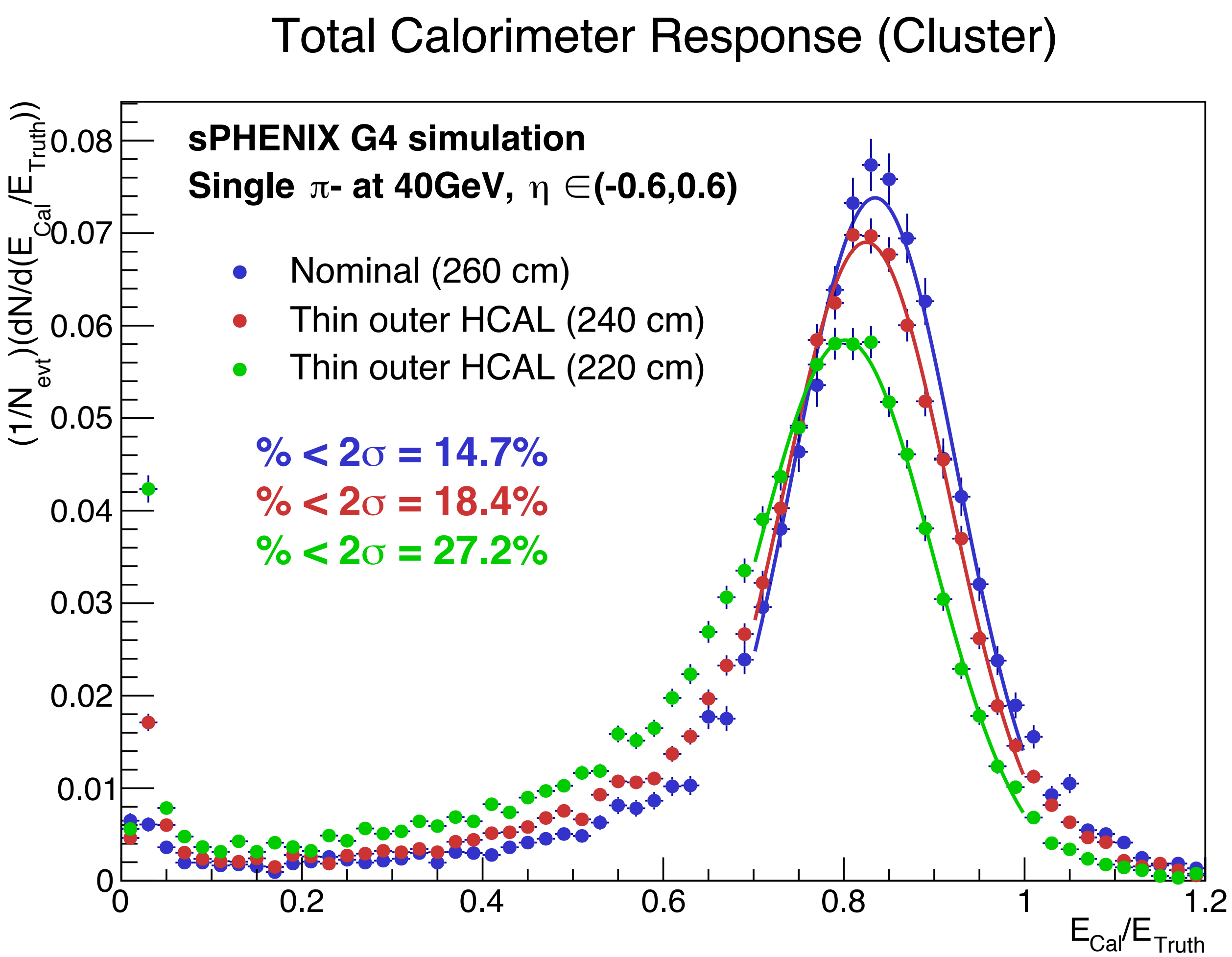


- Examining effect of different calo stack configurations
    - ➡ “final” version of studies for ALD charge

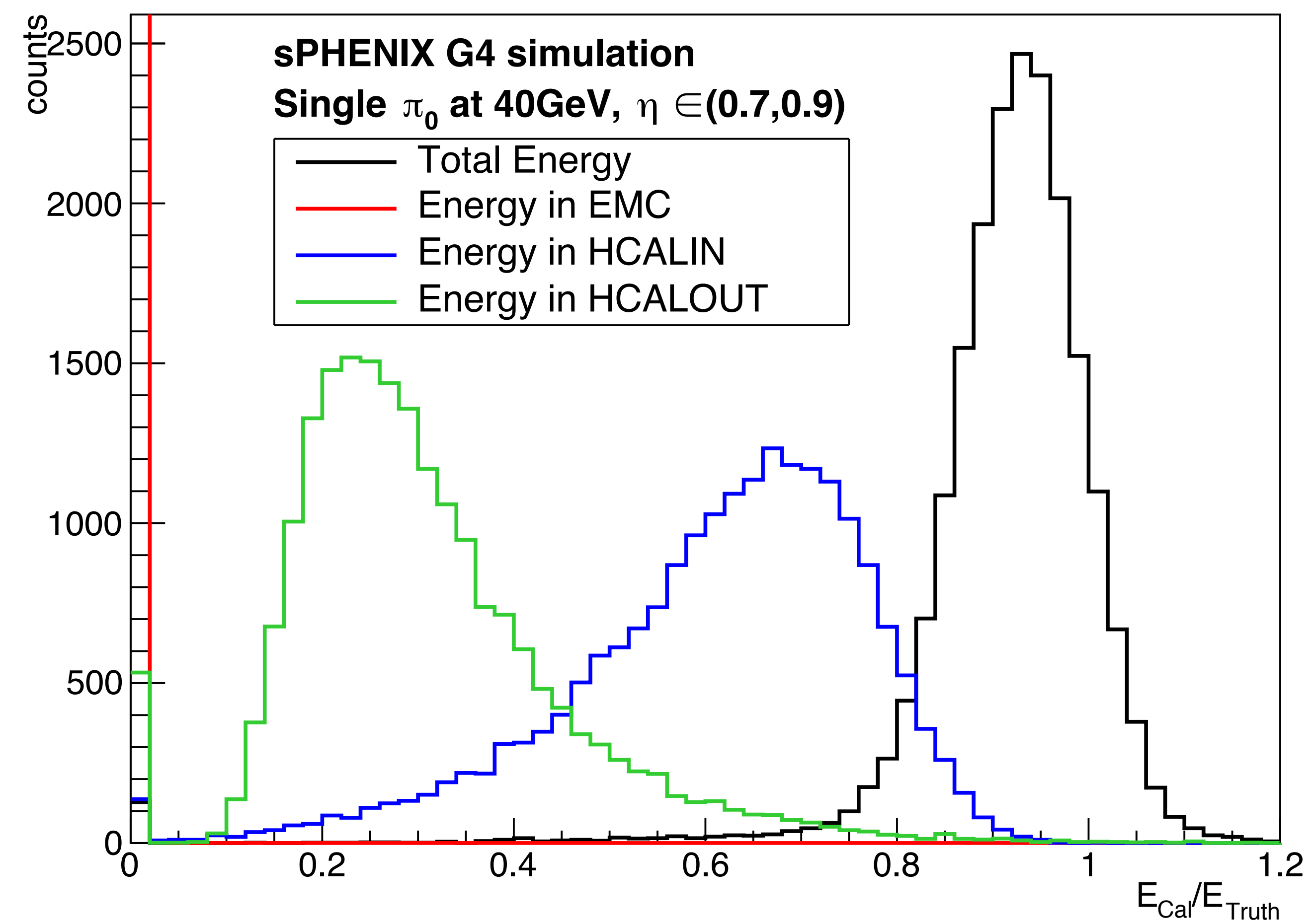




3. Hadron response studies

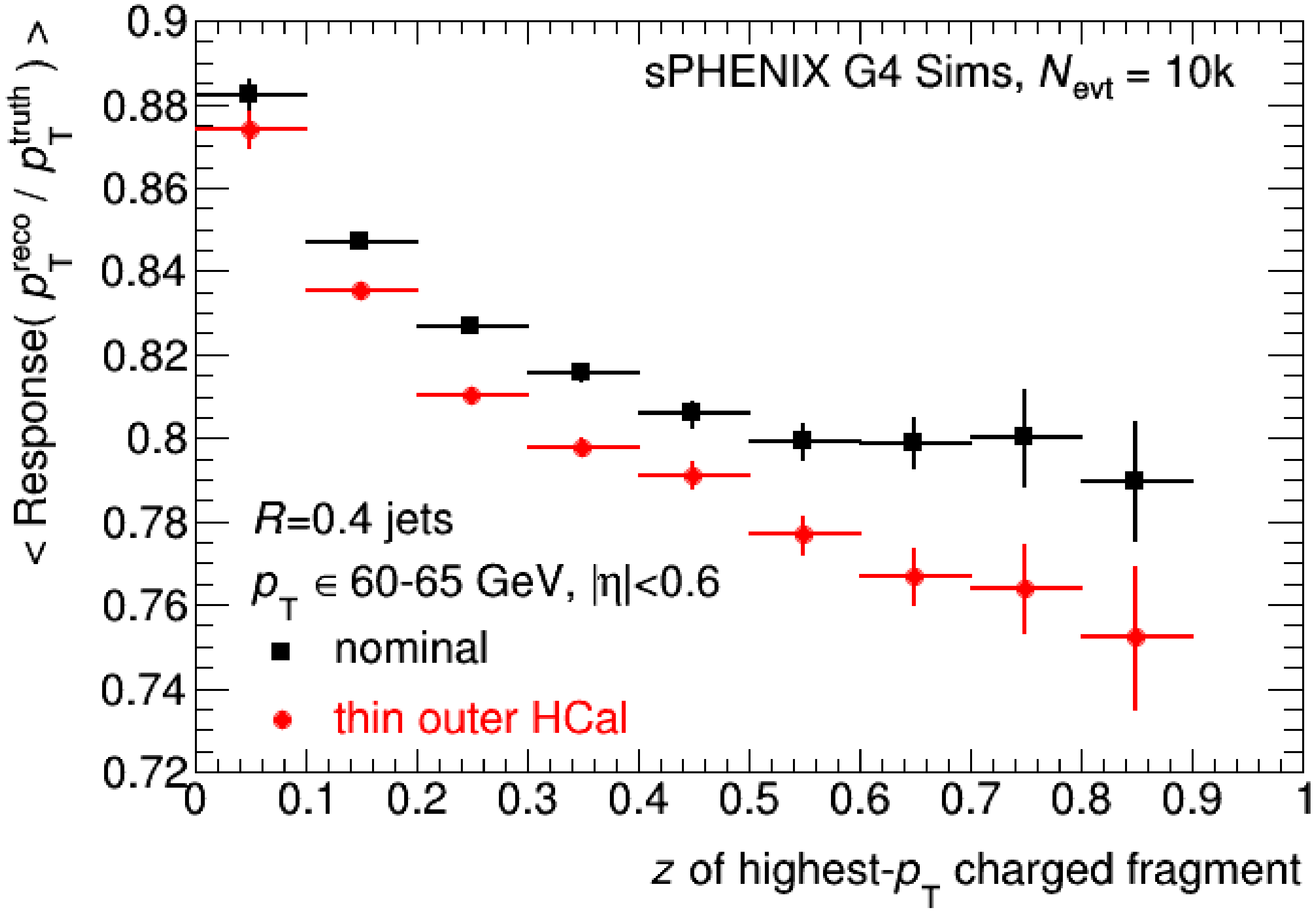


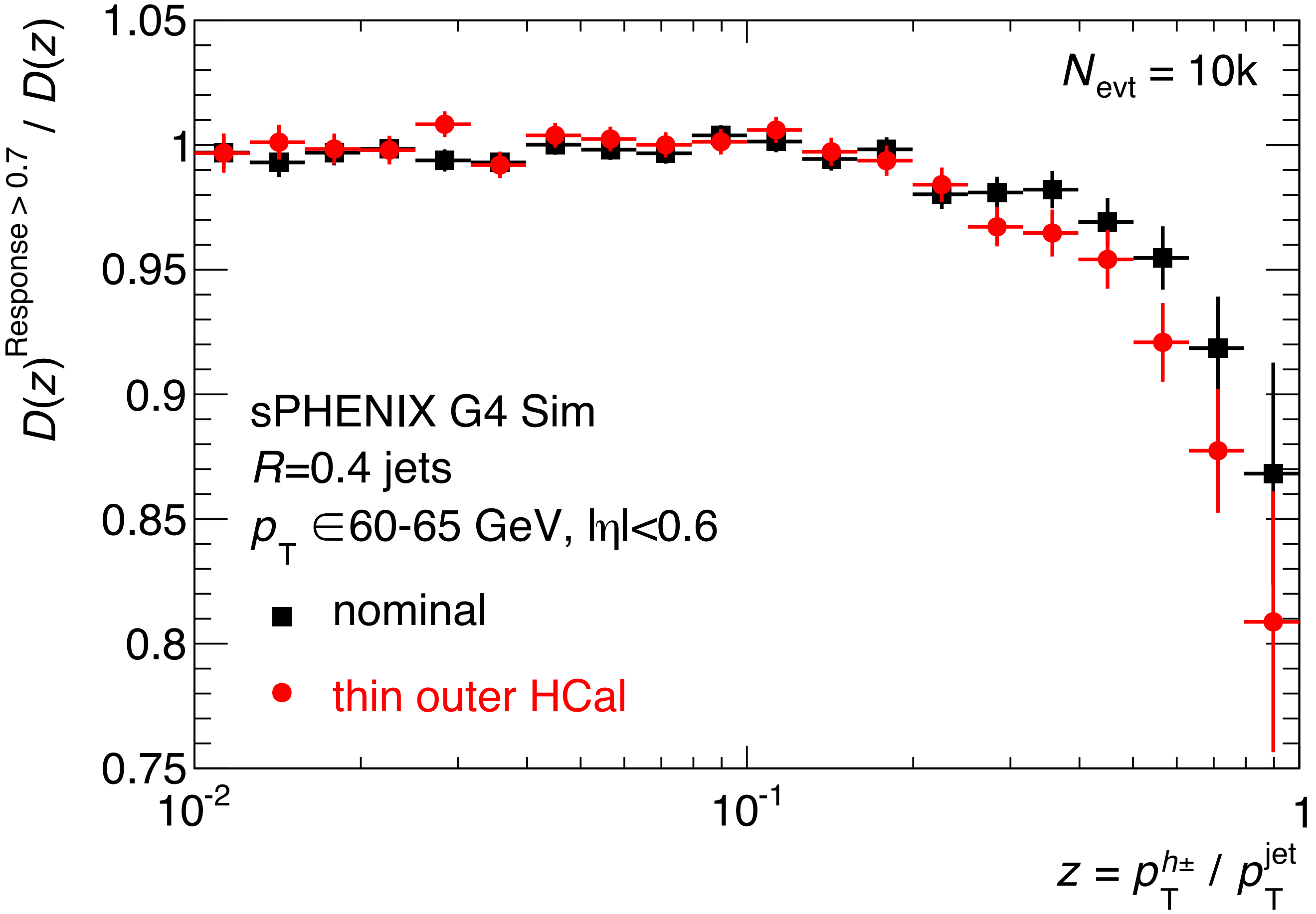
Misses EMC: eta = (0.7,0.9)



- Single hadron response studies by Kurt Hill (Colorado) and Sarah Campbell (Columbia)
- *Left*: with thin OHCal, rate of punch through hadrons increases
- *Right*: with reduced-η EMCal, EM energy ends up in the I+OHCal

3. Biases on FF measurements





How max-z_{ch}-dependent is the calo-only jet response?

What is the bias on an FF measurement if one only includes high-response jets?

3. EMCal clustering: Island alg

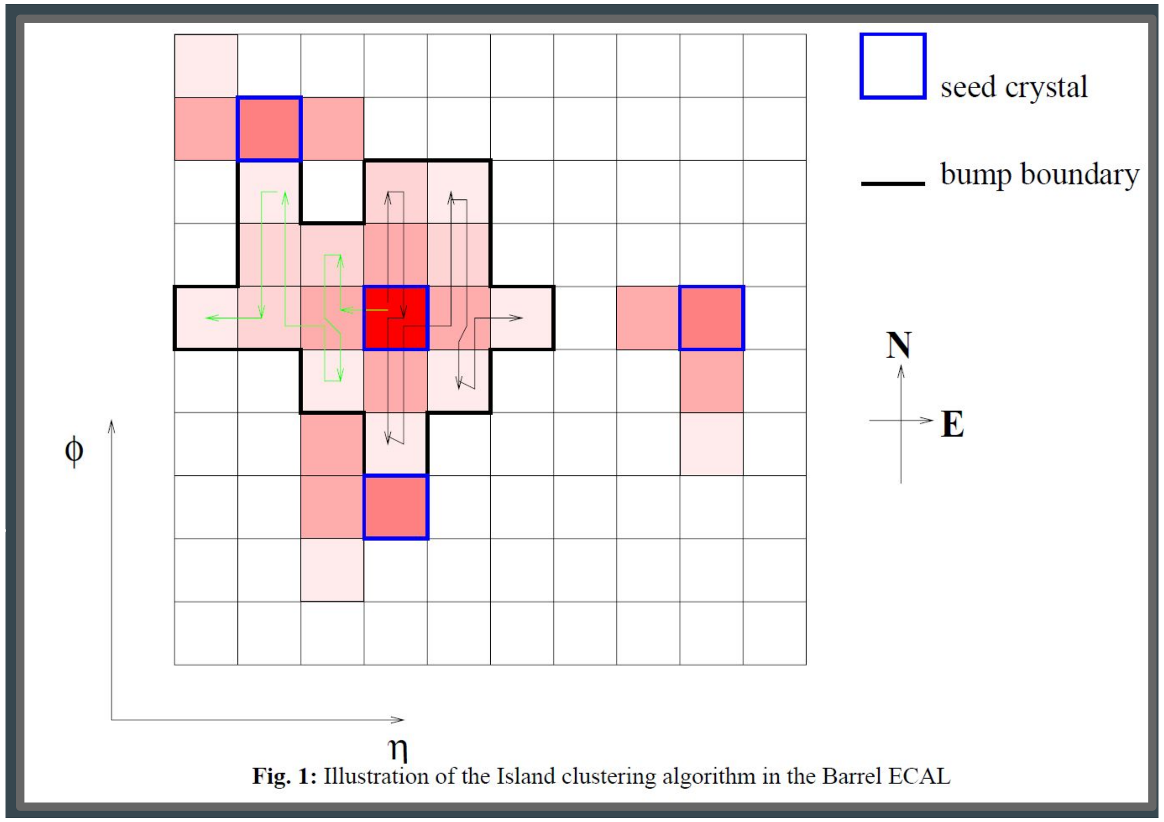
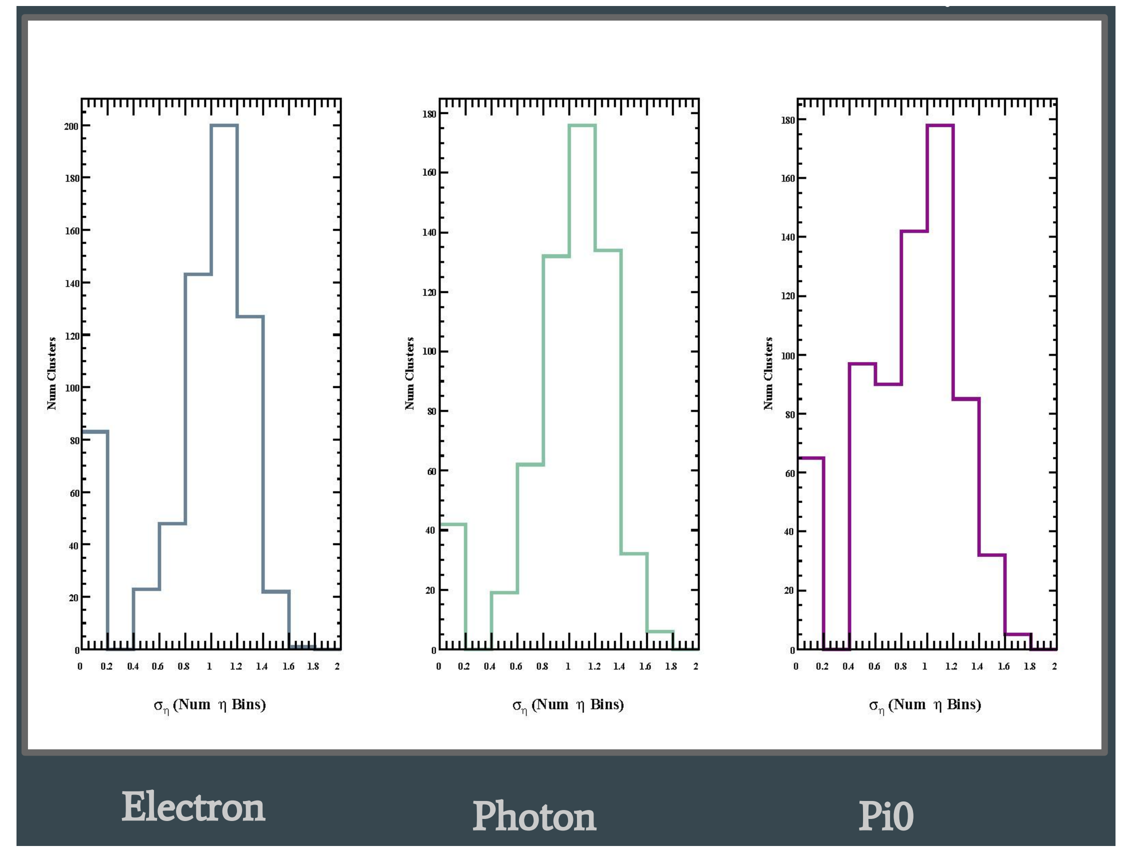
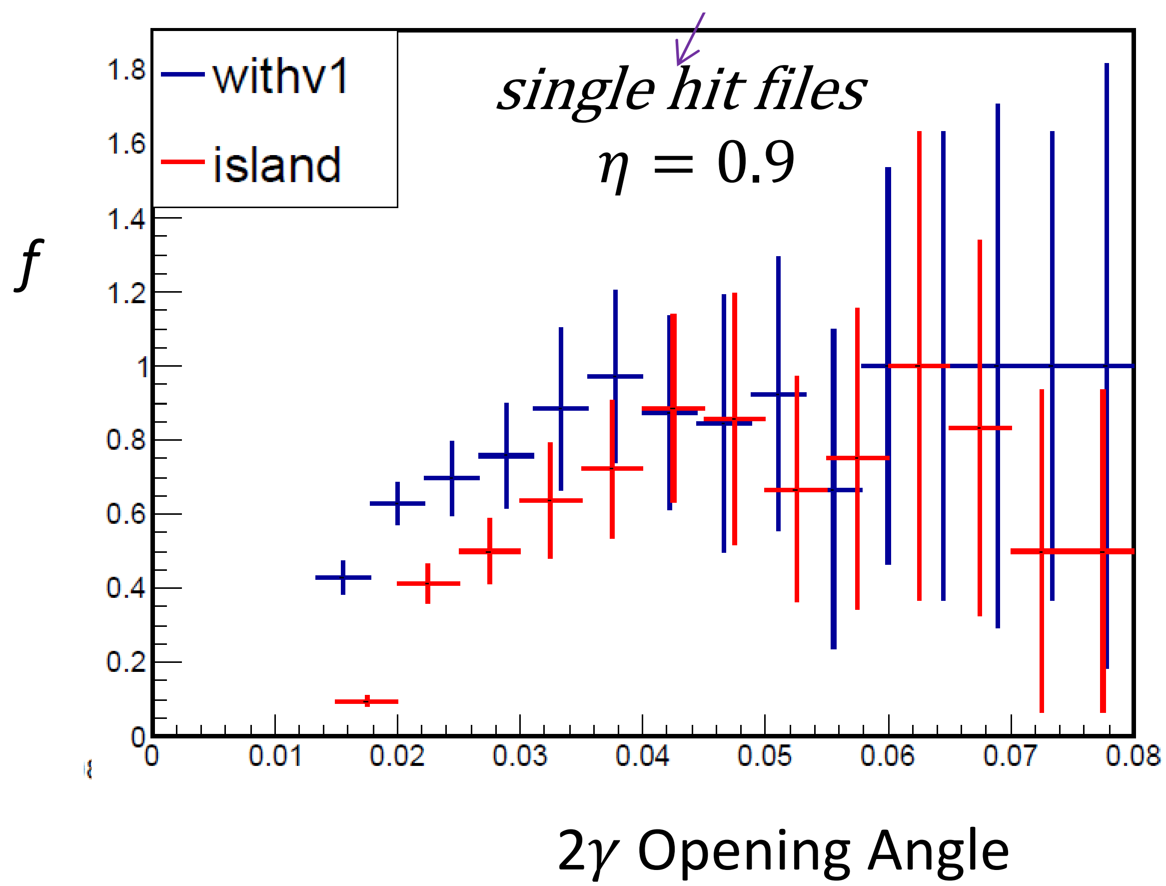


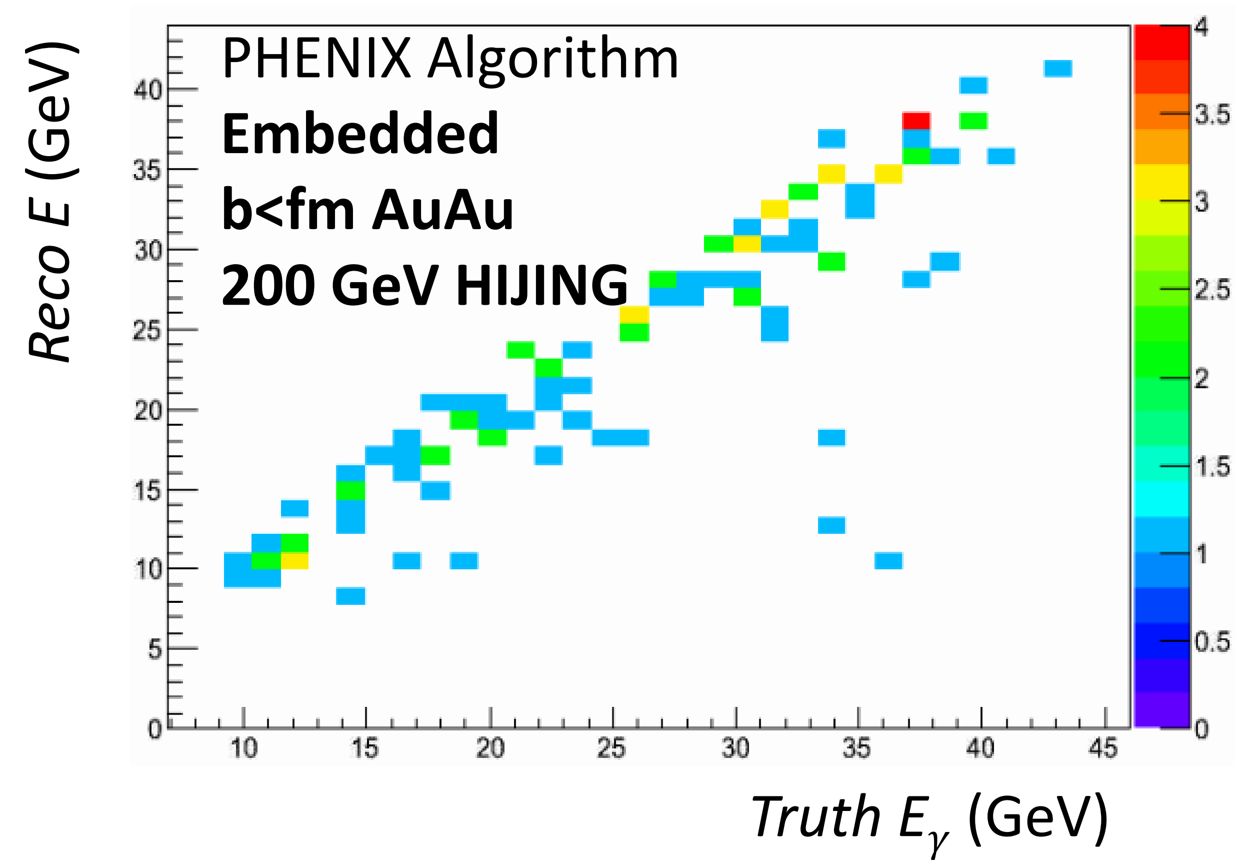
Fig. 1: Illustration of the Island clustering algorithm in the Barrel ECAL



- Implementation/testing of CMS Island Algorithm by Brandon McKinzie (MIT summer student)
  - ➡ test of photon kinematics reconstruction
  - ➡ and shower shapes for $e^{\pm}/\gamma/\pi^0$
- Goal: benchmark, make usable by analyzers

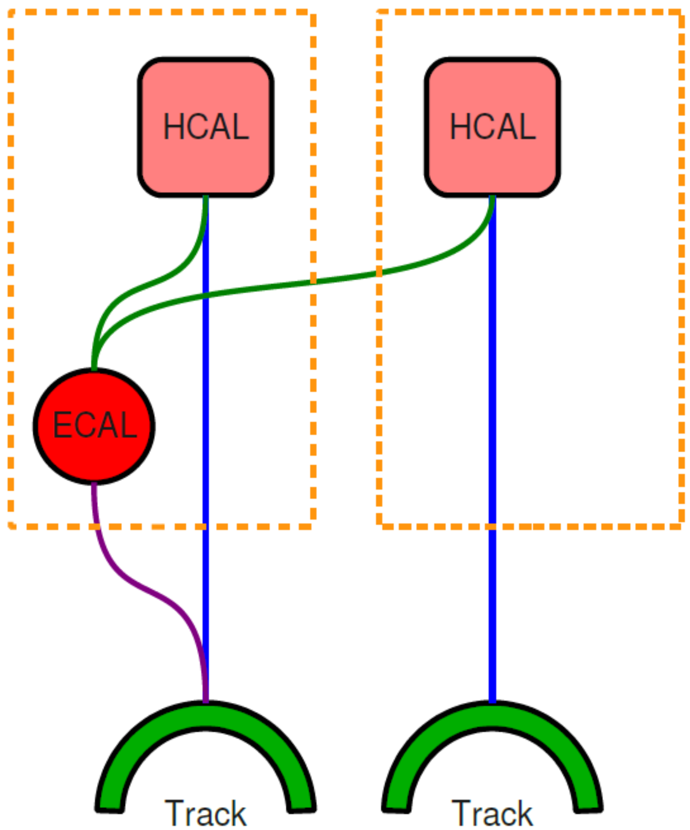
3. EMCal clustering: PHENIX alg.





- Implementation/testing of PHENIX clustering algorithm by Justin & Ohio U group
    - ➡ particular focus on splitting probability (ɣ vs. π^0 differentiation at low-p_T)
    - ➡ also testing reconstruction in central Hijing events
- Goal: modifications (if any) to make more appropriate for sPHENIX?

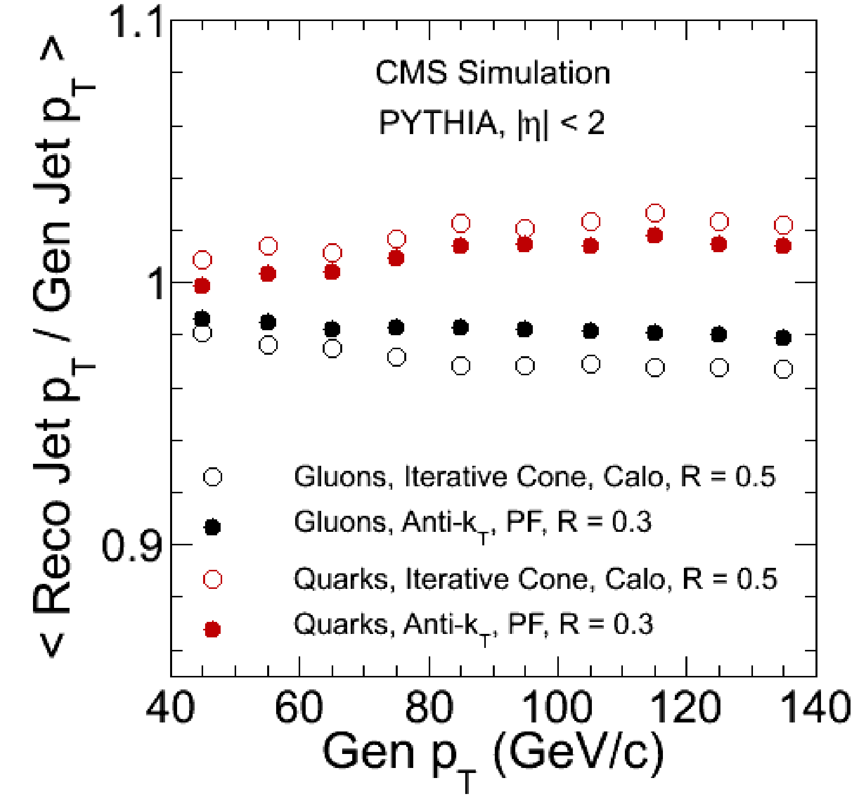
3. Particle Flow in CMS



- If E > p + 1.2 * √p then neutral particles are also created
- If the excess (E - p) comes only from:
  - HCAL → h^0 ($E - p$)
  - ECAL → γ ($E_{ECAL} - p/b$)
- If excess from both ECAL and HCAL:
  - $E_{ECAL} > E - p$ → γ $\left(\frac{E-p}{b}\right)$
  - $E_{ECAL} < E - p$ → γ (E_{ECAL})

    h^0 (remainder)
- Photon production given precedence

Corrected response to quark and gluon jets



Using PF heavy-ion configuration

- Comprehensive overview by Yen-Jie (MIT). A few observations:
  - ➡ extensive MC studies necessary to make algorithm perform well
  - ➡ benefits over Calo-jets are observable dependent — e.g. resolution for inclusive jet measurement may improve only modestly, but give a superior FF-dependence

3. Particle Flow in sPHENIX?

	CMS	ALEPH	ATLAS	sPHENIX
Magnetic field	3.8 T	1.5 T	2 T	1.5 T
Lever arm	1.29 m	1.8 m	1.4 m	-
Bending power	4.9 Tm	2.7 T.m	2.8 Tm	-
Pion reconstruction efficiency ($p_T = 5$ GeV)	90-95%	99%	90-95%	95%
Tracker thickness at $\eta = 0$ (λ_I)	0.35	0.02	0.4	-
ECAL Molière radius	2.2 cm	1.6 cm	4.0 cm	-
ECAL granularity	0.017×0.017	0.015×0.015	0.025×0.025	0.025x0.025
ECAL resolution	$\frac{3\%}{\sqrt{E}} \oplus \frac{12\%}{E} \oplus 0.3\%$	$\frac{18\%}{\sqrt{E}} \oplus 0.9\%$	$\frac{10\%}{\sqrt{E}} \oplus 0.17\%$	$\frac{15\%}{\sqrt{E}}$
ECAL longitudinal segmentation	no	yes	yes	-
HCAL granularity	0.085×0.085	0.06×0.06	0.1×0.1	0.1x0.1
HCAL resolution	$\frac{110\%}{\sqrt{E}} \oplus 9\%$	$\frac{85\%}{\sqrt{E}}$	$\frac{55\%}{\sqrt{E}} \oplus 6\%$	$\frac{120\%}{\sqrt{E}}$

- By the numbers, neither in “ATLAS” nor “CMS” camp
- Initial studies of PFlow benefits in sPHENIX have not found substantial improvements
  - ➡ challenge for TG: how to efficiently determine physics payoff of this approach?

4. Future activities

- Some key efforts where we hope to see progress in the future:
  1. Sensitivity of response to flavor & quenching
     - ➡ interface with HF TG on truth-level flavor tagging & on tagged *b*-jet response
  2. Photon ID & isolation atop UE background
  3. Track-to-calo matching (initial work by CU, update?)
  4. Fake jet rejection & recoil jet / event mixing
  5. Unfolding challenge to recover quenched distributions
- Planning to have more “invited” talks, e.g. M. Verweij on substructure, A. Angerami on unfolding techniques, etc.
  - ➡ also plan to interface closely with JETSCAPE
- Many opportunities for new JS members to have “ownership”
  - ➡ <u>*every half-time student or post-doc potentially makes a big difference*</u>

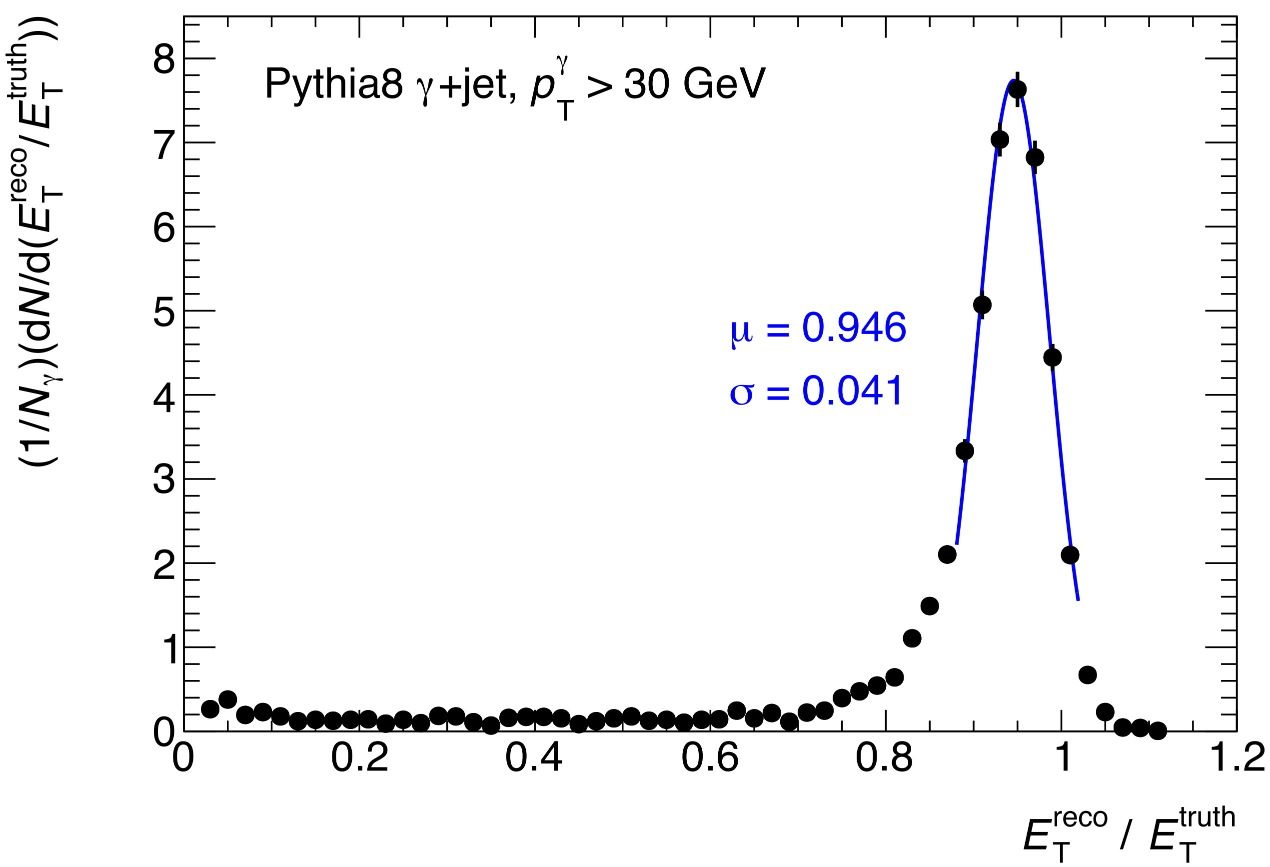
5. Plan for Quark Matter

- Proposed strategy: coordinated set of performance plots all looking at different aspects of a specific event sample
  - ➡ multiple suggestions to focus on photon+jet events (tests EMCal, HCal, tracking simultaneously)
    - ➡ also, interesting physics potential
  - ➡ according to our pQCD-based projections in the MIE proposal document: sPHENIX will sample 600 billion Au+Au events
    - ➡ *expect ~10k events with p_T^{γ} > 30 GeV in 0-20% collisions*
- Deliverables for QM:
  1. performance for photon, jet, track measurements in *pp* and Au+Au
  2. statistical projections for distributions of interest
- In the next few slides: a peek at basic performance quantities
  - ➡ analyzers are invited to study these in more detail — conveners are committed to helping you get started!

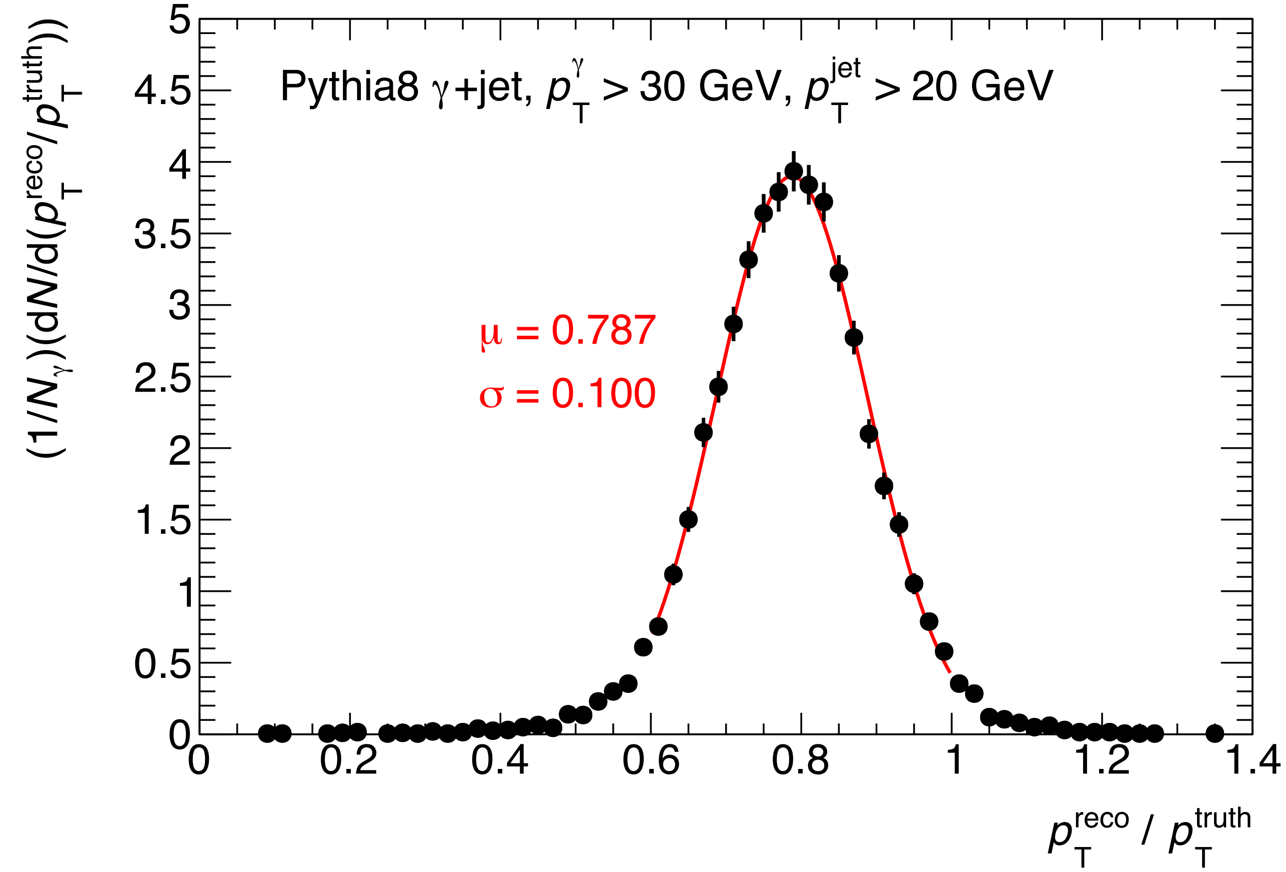
5. Photon-jet event sample

- Generated sample of 10k Pythia8 photon+jet events with the following generator-level requirement:
  - ➡ truth photon with $p_{T\gamma}$ > 30 GeV in $|\eta_\gamma|$<1
  - ➡ at least one R=0.4 truth jet with p_T^{jet} > 20 GeV in $|\eta^{jet}|$<0.6
- Full G4 simulation (tracking has same configuration as in September 2016 tracking review: ITS (cylindrical geometry) + IT + TPC)
  - ➡ *pp* events at the moment, will incorporate embedding
  - ➡ thanks to Chris P. for real-time debugging of HCal geometry issues
- Input HepMC files: /phenix/upgrades/decadal/dvp/GeneratorInputFiles/PhotonJet/
- Output G4 HITS files: /sphenix/sim/sim01/production/photonjet/2016_12_13/
  - ➡ total event statistics match expected # of events in data

5. Photon & jet p_T performance

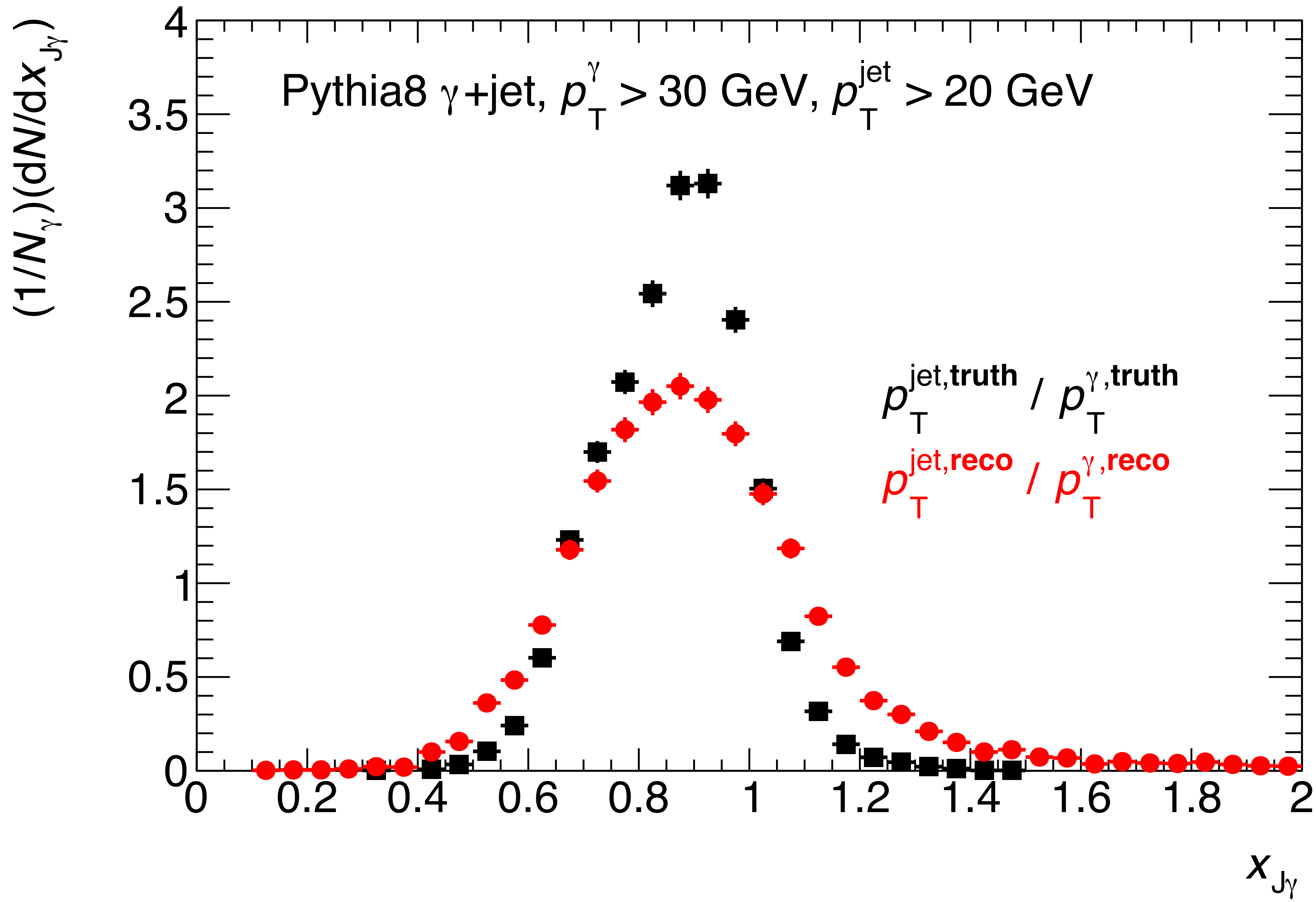


matching truth photons to nearest *CEMC* cluster (default sPHENIX alg.)



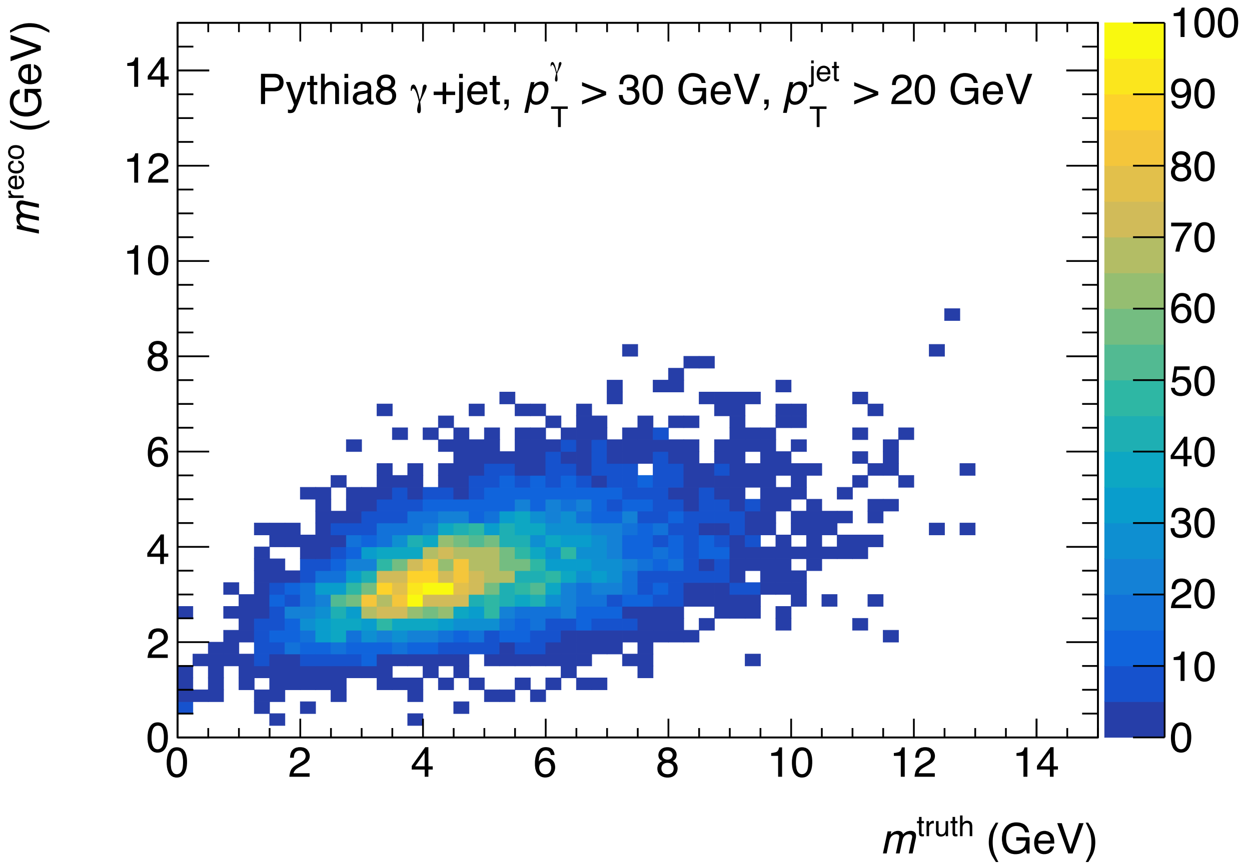
matching truth jets to nearest *R*=0.4 tower jet

5. Detector effects on photon-jet balance

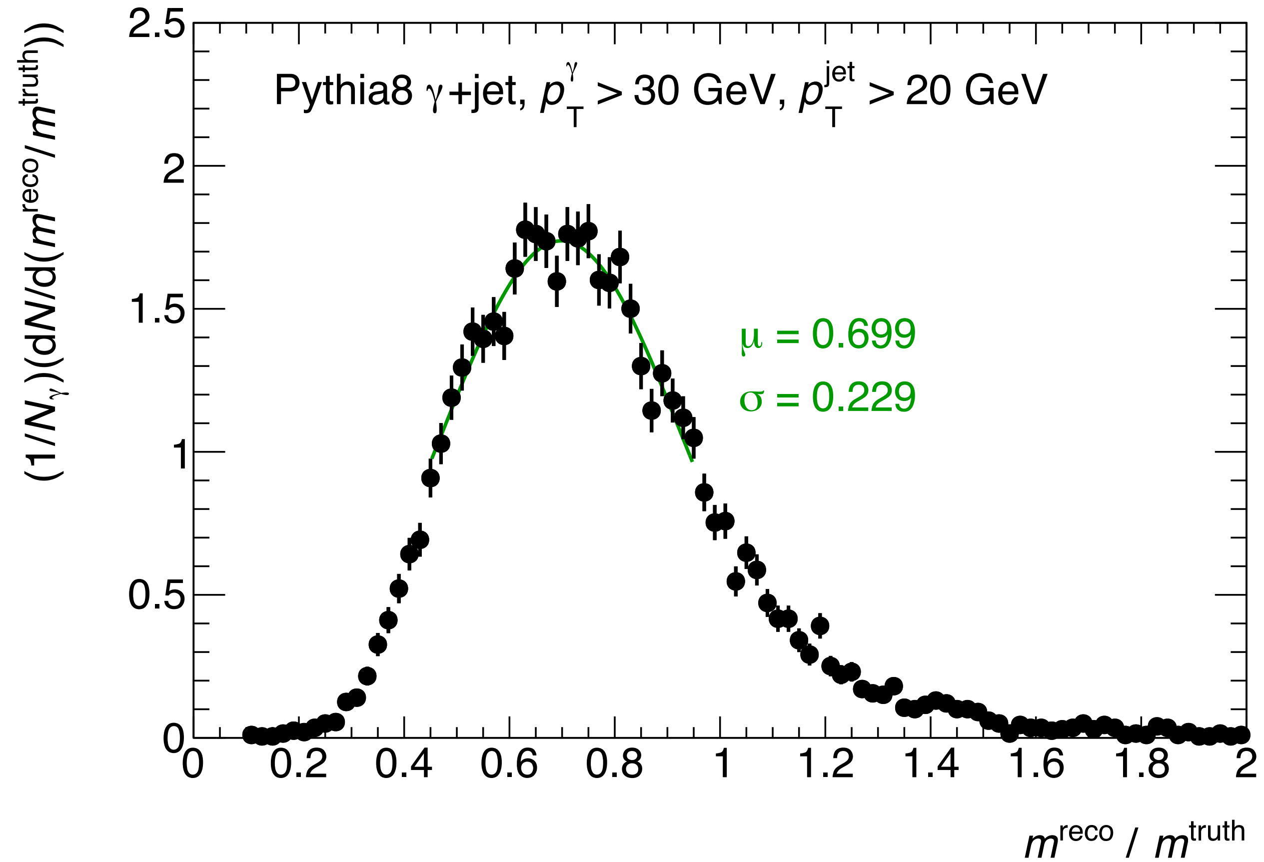


$p_T^{\gamma,\text{reco}}$ and $p_T^{\text{jet,reco}}$ corrected for overall response (1/0.946 and 1/0.787, respectively)

5. Jet mass performance

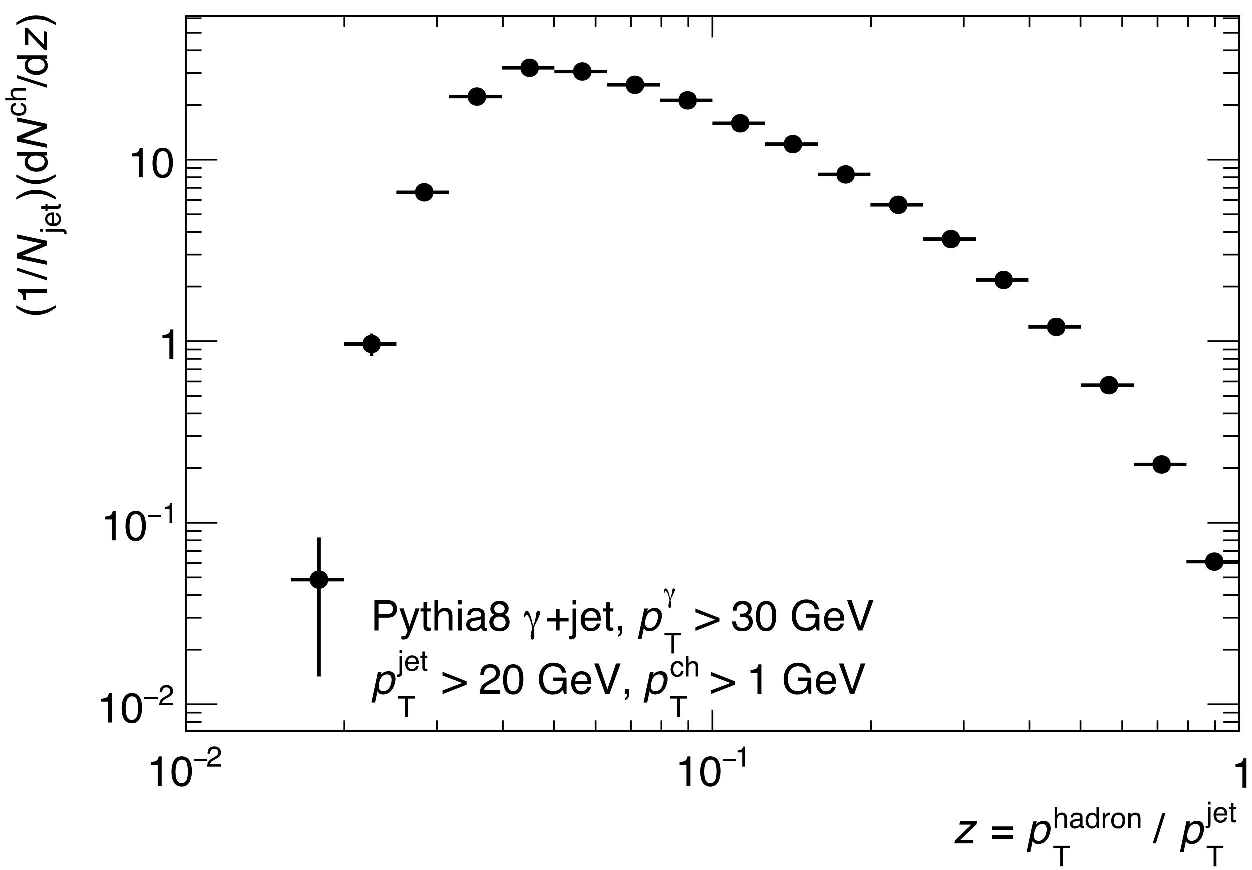


scatterplot of truth (particle-based) and reconstructed (calo-tower-based) jet mass

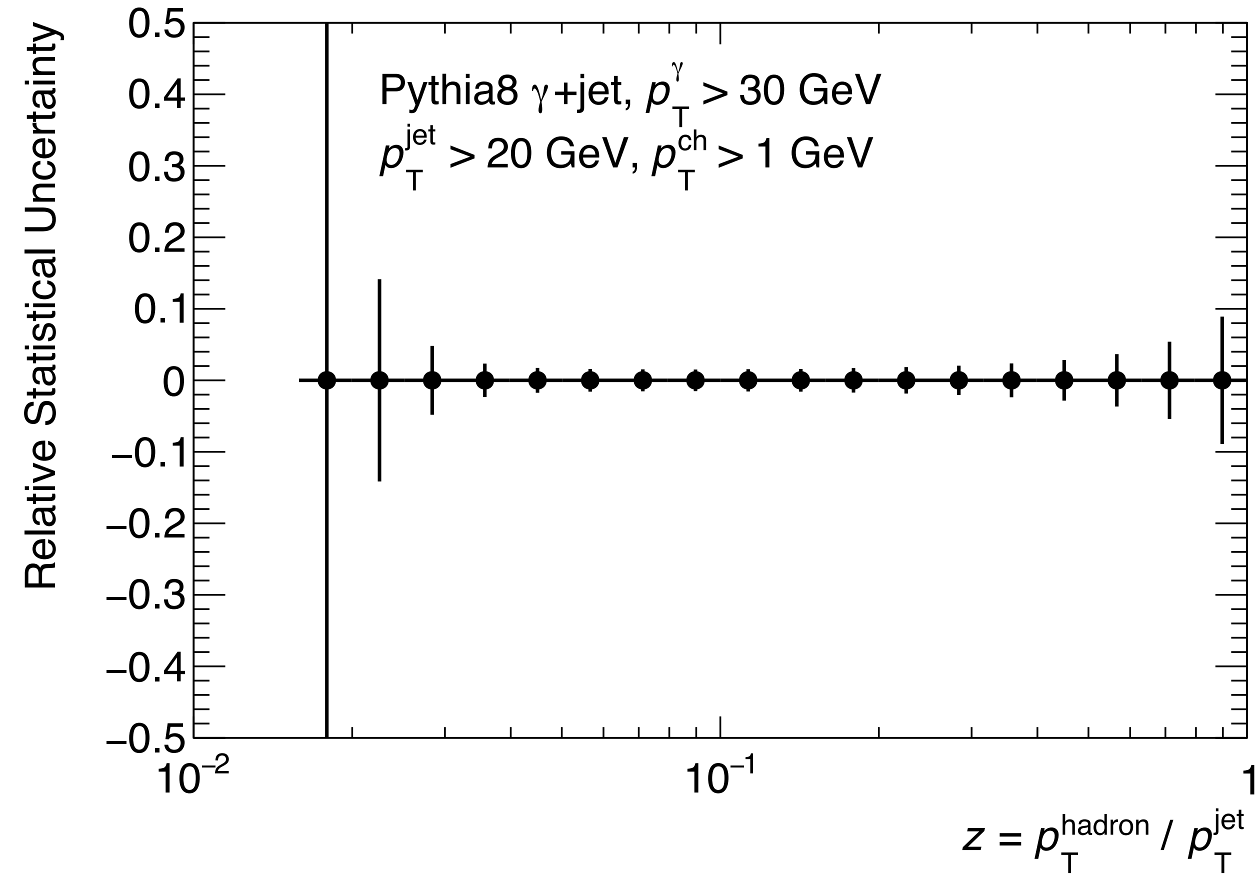


distribution of jet mass “response”

5. γ-tagged FF statistical projection

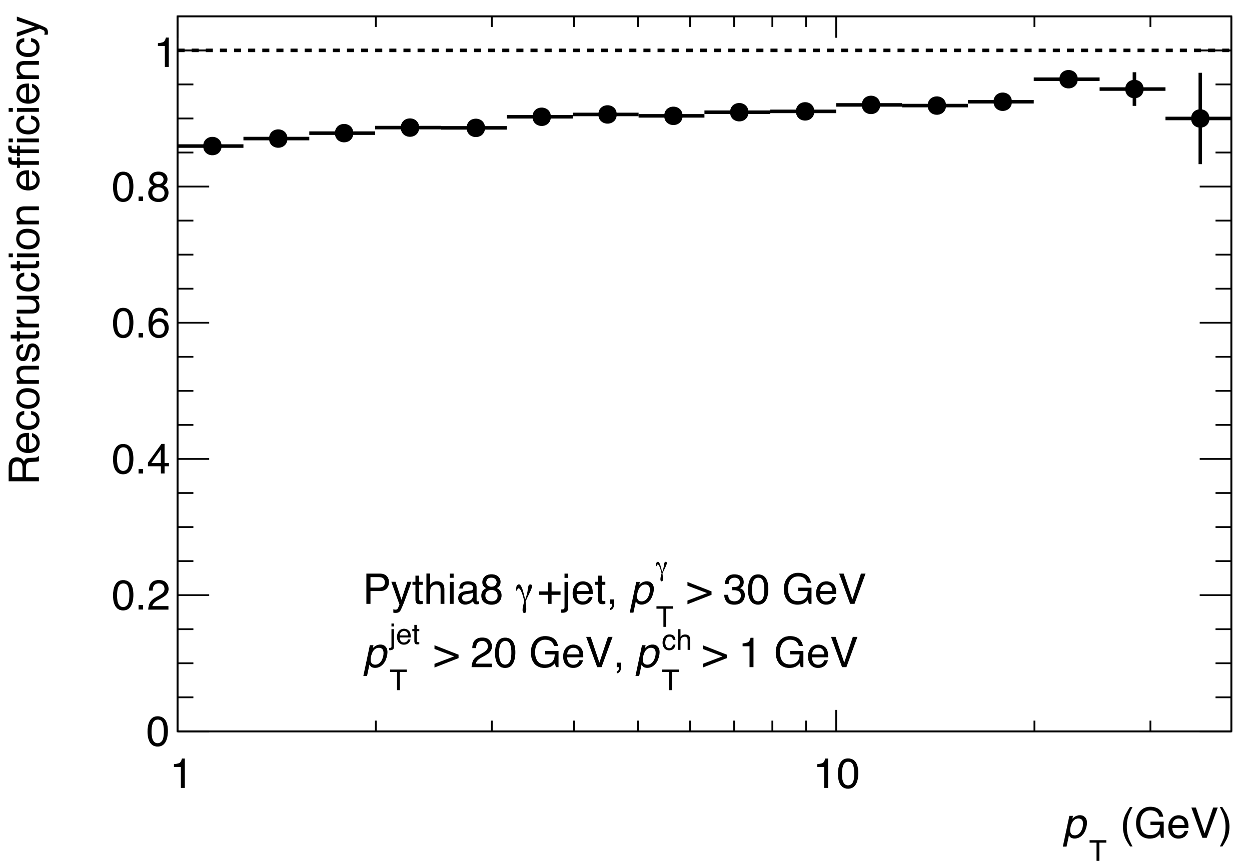


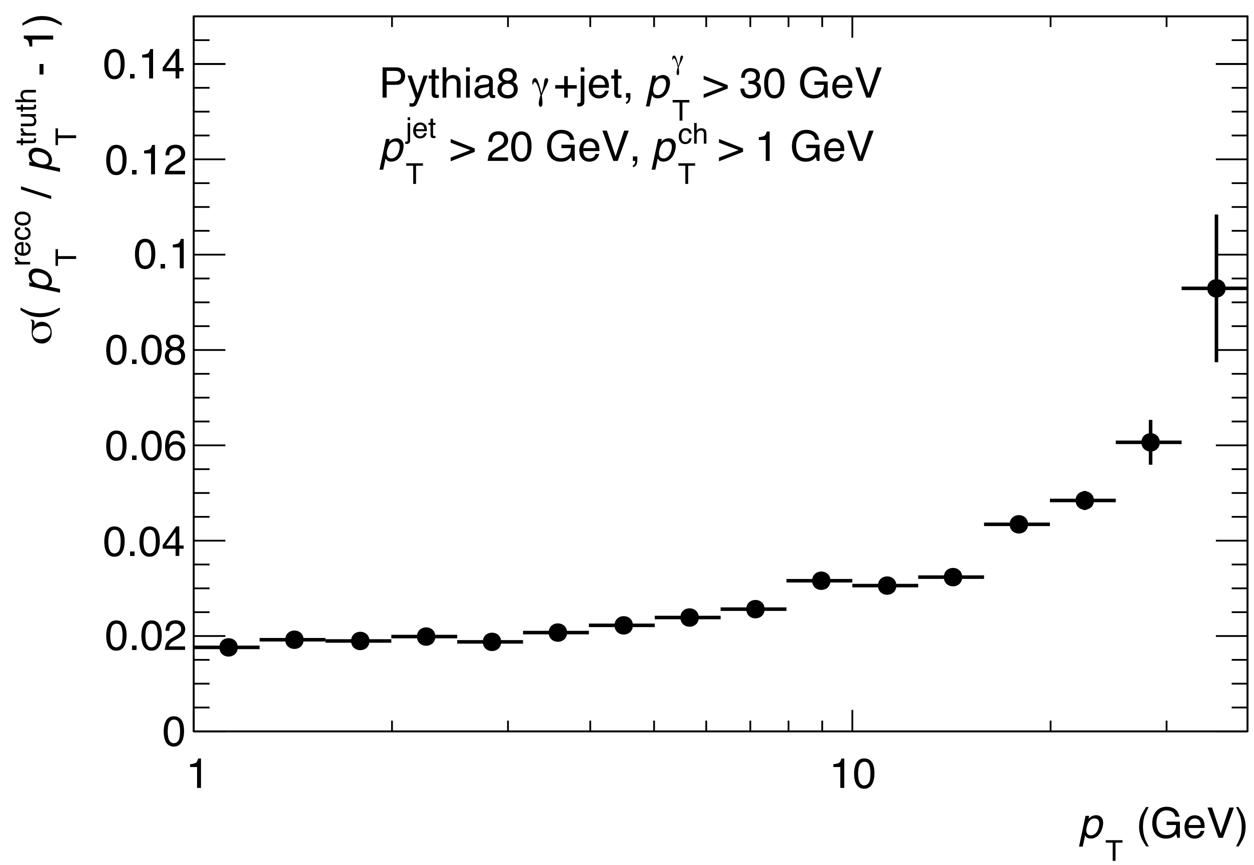
truth-level fragmentation function in 10k events, p_T^{hadron} > 1 GeV



relative statistical uncertainty

5. Tracking performance





Charged hadron reconstruction efficiency

Charged hadron p_T resolution

volunteers welcome!

Thank you!

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2. The evolving physics picture
3. Summary of activities in the TG
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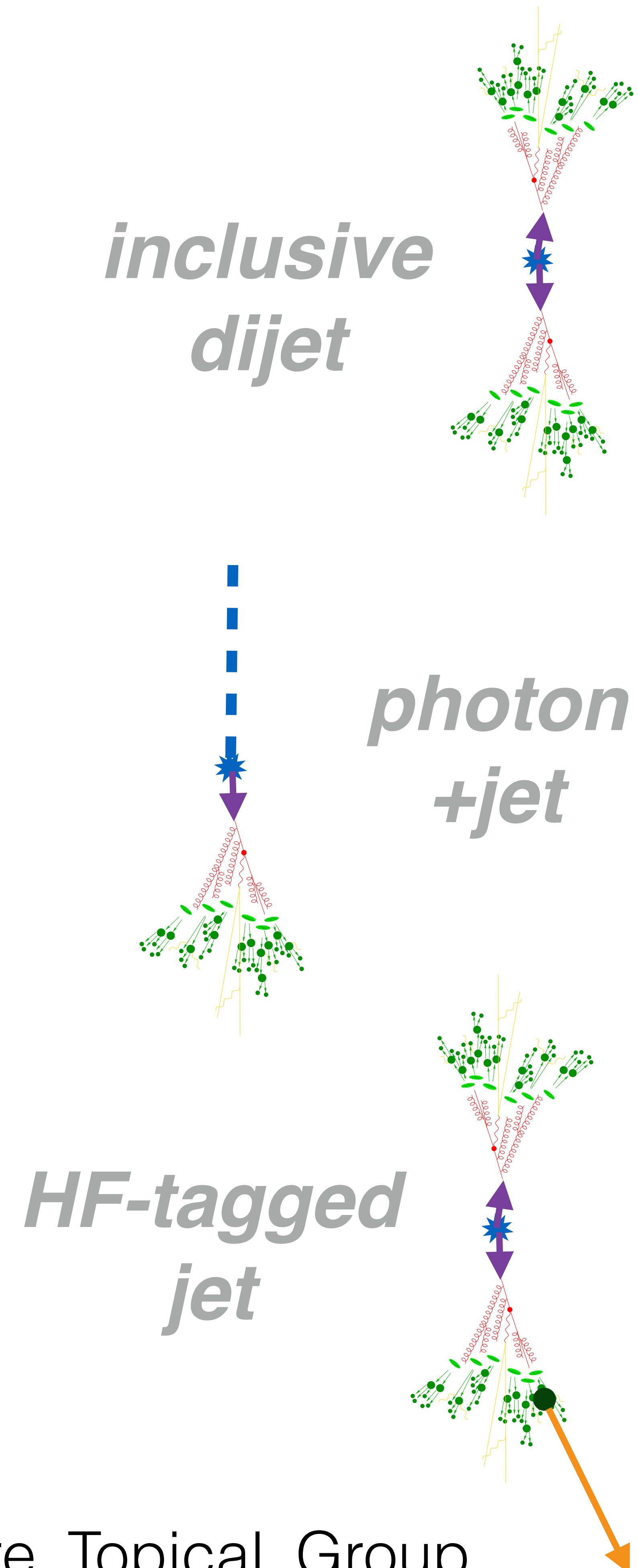

https://wiki.bnl.gov/sPHENIX/index.php/Jet_Structure_Topical_Group